Retrofitting Hub Motors to the Un-Driven Wheels of Fossil Fuelled Vehicles, With a Comparison of a Flywheel Energy Storage Systems (FESS) and a Traditional EV Battery

Faculty of Health, Engineering, and Sciences
University of Southern Queensland Toowoomba

Matthew Brinkmann

[redacted]

Supervisor: Professor John Billingsley

15th of October 2023

Declaration

Retrofitting Hub Motors to the Un-Driven Wheels of Fossil Fuelled Vehicles, With a Comparison of a Flywheel Energy Storage Systems (FESS) and a Traditional EV Battery.

Submitted by: Matthew Brinkmann
Student Number: [redacted]

Declaration:

I declare that the work reported in this thesis is entirely my own effort, except where otherwise acknowledged. I also declare that the work is original and has not been previously submitted for assessment in any other course of study, at any other University.

Signatur[redacted]
Date 15/10/2023

Contents

Abstract

This honours thesis presents an exploration of retrofitting electric motors to the undriven wheels of a fossil fueled vehicle, with a comparison of energy storage systems between a flywheel energy storage system and a lithium-ion battery, with the aim to increase kilometres driven per litre of fuel in urban areas. The desired outcome is to enhance energy storage and efficiency and increase the overall efficiency of urban driving in various automotive applications. As the demand for clean and sustainable energy sources continues to grow, the retrofitting of electric motors to fossil fuelled vehicles offers a promising solution. This dissertation aims to evaluate the feasibility and potential benefits of retrofitting electric motors with either a flywheel energy storage system or a Lithium-ion battery energy storage system. Specifically investigating the potential benefits of increased energy density, potential for extended range, minimisation of emissions, and improved overall performance. Through an in-depth analysis of existing research and case studies, this thesis examines the technical aspects, challenges, and economic implications associated with retrofitting electric motors to fossil fuelled vehicles. Additionally, it explores the potential for environmental advantages and potential impact on energy consumption and carbon emissions.

Abbreviations List

AC - Alternating Current
ACT - Australian Capital Territory
AVR - Automatic Voltage Regulator
BERS - Braking Energy Recovery System
BEV - Battery Electric Vehicle
BLDCM - Brushless Direct Current Motor
cm - centimetre
DC - Direct Current
EMF - Electromotive Force
EOL - End of Life
EV - Electric Vehicle
ESS - Energy Storage System/s
FBD - Free Body Diagram
FCEV - Fuel Cell Electric Vehicle
FES - Flywheel Energy Storage
FESS - Flywheel Energy Storage System
GHG - Green House Gasses
HEV - Hybrid Electric Vehicle
ICE - Internal Combustion Engine
ICEV - Internal Combustion Engine Vehicle
KE - Kinetic Energy
km/h - Kilometres Per Hour
kW - Kilowatt
kWh - Kilowatt Hour
kWm - Kilowatt Minutes
LIB - Lithium-Ion Battery
Li-ion - Lithium-ion MJ - Mega Joules
ml - Millilitre
MPa - Megapascals
m/s - meters per second
m/s^2 - meters per second squared

PHEV - Plug in Hybrid Electric Vehicle
PPE - Personal Protective Equipment
PREB - Pneumatic Regenerative Energy Braking
PREBS - Pneumatic Regenerative Energy Braking System
R/C Car - Remote Controlled Car
RPM - Revolutions Per Minute
SME - Subject-Matter Expert
SM - Shear Modulus
UTS - Ultimate Tensile Strength
Wh - Watt hour
YS - Yield Strength

Figures List

Tables List

1 Introduction

This project explores the concept of increasing the kilometres driven per litre of fuel in urban areas.Urban driving and rural driving fuel consumption differs quite significantly (Fan et al., 2023). This project aims to explore the feasibility of utilising electric vehicle (EV) technology and retrofitting to fossil fuelled cars in order to increase fuel efficiency in urban areas, which in turn could have a multitude of positive benefits. Specifically, it will focus on the retrofitting of electric motors / generators to recoup the energy lost braking in fossil fuelled vehicles, as well as explore the possibility of using a flywheel energy storage system (FESS). A Braking Energy Recovery System (BERS) has proven to be an integral part of the EV revolution (Beno et al., 2001), and its utility in achieving this outcome will be discussed in this thesis. The aim of this honours' thesis is to analyse whether it would be feasible to mount in wheel motors to the un-driven wheels of a fossil fuelled vehicle, whilst using either a lithium-ion battery (LIB) versus a flywheel energy storage system (FESS) as the energy storage device (ESS). An in-wheel motor is an electric that is incorporated into the hub of a wheel (Watts et al., 2010). The terms LIB and chemical battery, and mechanical battery and FESS, car and vehicle, will be used interchangeably throughout this thesis. Research has been conducted into retrofitting electric motors to existing fossil fuelled vehicles with the aim of decreasing fuel consumption, increasing range and minimisation of greenhouse gasses. This project differs as the research question relates to increasing the fuel efficiency for the average vehicle to be in line with the fuel consumption of the vehicle during highway travels.

The law of conservation of energy states that energy can neither be created nor destroyed, energy can only change from one form to another. Large quantities of energy are lost every day through general braking activities of vehicles. Regenerative braking is one form of energy recuperation that allows for energy to be extracted and then stored and reused (Gao et al., 1999). The significance of this technology means that it has the ability to minimise energy loss. Regenerative braking occurs when the brakes of electric or hybrid vehicles are applied by the driver. Current technological restrictions in the automotive industry mean that regenerative braking is unique to EV's and Hybrid electric vehicle (HEV)'s, due to the way in which propulsion is applied to the wheels (Hartley et al., 2011). If there was a way to retrofit this technology to fossil fuelled cars, it would allow for fossil fuel vehicles to recuperate spent energy. The main advantage and reason for this project is creating a more efficient system in fossil fuelled cars. The importance of this could be seen on a smaller and larger scale. The perceived benefit of this on a larger scale in society would be the minimisation of energy expenditure and subsequently the reduction in use of fossil fuels by creating a more efficient energy system. It could have other benefits on a smaller scale to the average driver including decreased fuel costs. Hence, the reason this concept should be explored is for the potential benefits to society as a whole (Luz, 2022).

The idea of electrifying propulsion systems for road going vehicles has been a topic for over a century. Further to this, hybrid propulsion systems for vehicles were first investigated over a century ago (McGuire, 2023). Initially, their purpose was a new way for man to be able to minimise travel times. During recent times, it has proven to be a significant movement within the automotive and transport industry (Babar et al., 2020). Although there are many perceived qualities, including increased acceleration and a quieter driving experience, this is not the driving force behind its uptake. Currently, there is the desire to change the energy source that is used in the transportation of goods and people (Babar et al., 2020). The main reason for this being the push to minimise harmful emissions, and minimise the overall carbon footprint on the earth. As the earth's population grows, the concern for minimising Green House Gasses (GHG) is increasing, with many believing that electrification of vehicle propulsion systems is a part of the solution (García-Afonso & González-Díaz, 2023). There is a big push from both governments and social requirements for the continued adoption of the EV way of life (Luz, 2022). However, the application of this is in reality raises numerous obstacles.

Firstly, it isn't financially feasible for the majority of the country's population to purchase a new car. Secondly, the Australian power grid would have to increase power generation by 46% to sustain power requirements of EV's (Brakels, 2022). Lastly, Australia relies on fossil fuels to generate the majority of electricity (Brakels, 2022), with an outrageous figure of around 71% (Ausgov,2023). Whilst EV's allow for reducing emissions within the transport industry, the power required to charge them is not derived from zero emission platforms (Brakels, 2022). This indicates a flaw in EV's, and that potentially retrofitting fossil vehicles could be a practical alternative. It could also reach a further market and thus have a bigger combined effect. Australia alone has over 20 million registered vehicles on our roads at this point of time (Mcgrath, 2019), which if retrofitted could have a huge impact on energy savings.

Initially, the research undertaken for this project was aimed at building a sound knowledge base of current technologies surrounding the EV and HEV industry. A review of information into the current advancements within the automotive industry was undertaken to understand the current technology. This knowledge basis allowed this thesis to determine the gaps in knowledge and how current fossil fuel systems can be manipulated to be more efficient. In conclusion, this project shall focus on comparing the efficiency of a LIB and FESS in conjunction with electric hub motors. This thesis will rely on mathematical models and calculations in order to determine the feasibility of the objectives and explore this gap of potential utilisation.

The cost to manufacture inclusive of the profit ratio's, will ultimately determine whether the project were to go into production stage. It's assumed that a battery may only need to hold a few kW minutes of energy in order to obtain suitable results for this thesis. A mechanical battery is likely to be much more expensive to manufacture for the intended purpose of this thesis despite the energy required. However, if it were able to prove to be an efficient system and depending on the final cost, it could potentially be an alternative to a LIB.

1.1 Objectives and Aims

The primary aim of this dissertation was to determine if it is feasible to increase the kilometres driven per litre of fuel in urban driving conditions through retrofitting electric motors to the un-driven wheels of a fossil fuelled vehicle.Further to this, is it feasible to use a FESS as the ESS instead of the traditional LIB. Further research was undertaken to ascertain a suitable energy storage device that can be used to store energy recouped through the regenerative braking process. This thesis will focus on comparing a mechanical (FESS) and a chemical battery (LIB) as the ESS. Calculations relating to efficiencies of the electrical systems and changes in power and energy generation will be discussed. These calculations will determine if there is further cause for research into this topic. Further aims of this thesis are to ascertain whether the objectives of this dissertation are reasonable and realisable.

1.1.1 Aim

The aim of this dissertation was to determine if it is feasible to increase the kilometres driven per litre of fuel consumed in urban driving conditions through retrofitting electric motors to the un-driven wheels of a fossil fuelled vehicle. Further to this, is it feasible to use a FESS as the ESS instead of the traditional LIB. A comparison between a LIB and a FESS will be explored.

1.1.2 Research Question

This project aimed to answer the following overarching research question:
Is it theoretically possible to increase the kilometres driven per litre of fuel consumed in urban driving conditions through retrofitting electric motors to un-driven wheels of a fossil fuelled vehicle using either a FESS or a LIB as an energy storage system?

1.1.3 Objectives

This was achieved utilising the following specific objectives:
The first objective of this thesis is to conduct research into appropriate mathematical modelling methods to ascertain the most appropriate course of action to enable batteries to be the form of ESS of this dissertation.

The second objective is to establish an understanding of key theories and background literature relevant to this project.

The third objective is to calculate the proportion of energy that can be harvested from slow down and acceleration process to determine viability.

The fourth objective is to investigate which is the most suitable system, a LIB or a FESS?

The fifth objective is to ascertain whether it is possible to gain more kilometres per litre of fuel in urban driving conditions with the regenerative energy system?

1.1.4 Thesis Organisation

This thesis has been divided into six chapters. Chapter two consists of the background literature review that explores the context of the problems and motivation for this thesis. It further explores relevant key information including mechanical and chemical batteries, as well as retrofitting technology. It also briefly explores consequences and ethics. The third chapter examines the methods that were used in this thesis, and the justification for choosing such methods. Chapter four proceeds to explore the results obtained from the mathematical model. Chapter five then goes on to discuss and interpret these results. This chapter also discusses the limitations of this thesis along with avenues for future research. Lastly, chapter six concludes the findings of this thesis and outlines the broader importance and relevance of this thesis.

2 Background

The idea of retrofitting electric motors to older existing fossil fuelled vehicles could be environmentally beneficial as well as cost-effective (Kaleg et al., 2015). Firstly, the vehicle that has been chosen for the conversion should be mechanically healthy. The reason for this is that there are less electronic components to remove, thus the process being less detrimental to the overall operation of the vehicle (Scott, 2020). The process of retrofitting electric motors and batteries to existing fossil fuel vehicles is an idea that is generating momentum to become a widespread reality (Evers, 2023). There are businesses that offer complete EV conversion kits to suit certain vehicles (wide variety for older Volkswagen rear-wheel drive vehicles) as well as a full drive-in drive-out ICE to EV conversion service. The main aim has been to retrofit electric motors and batteries to vehicles that are deemed lightweight and relatively easy to modify (Curry, 2022). Further, desired attributes of these vehicles are that the vehicles are pre CANBUS era as this makes the process easier. The CANBUS system is responsible for alerting the driver about faults with the vehicle along with managing automated system such as auto headlights and auto wipers. When removing the ECU, the CANBUS system goes along with it. The issue here is that the existing safety products like airbags, ABS Systems, headlights, seat belts and windscreen wipers cease to work (Goldberg, 2012).

BERS have shown the potential to increase fuel efficiency by 20 to 50% (Ahn et al., 2009). This figure depends on energy storage capacity as well as overall rolling mass of the vehicle. This energy efficiency increase is only related to EVs, PHEVs and HEVs that rely on a chemical battery as the ESS at this point in time. Research undertaken for this thesis has resulted in finding prototype systems using mechanical batteries as ESS, but not in a personal passenger vehicle as a form of ESS (Hedlund et al., 2015). This provides a gap in knowledge and a potential avenue for further research into the feasibility of this option. There are multiple businesses around the world that offer the service of a drive-in, drive-out electric vehicle conversion (Kuchta, 2022). This entails the business removing the internal combustion engine and ancillaries, such as the fuel tank and engine control unit (Kuchta, 2022). The rolling shell of a vehicle is then fitted with an appropriate electric motor/s and chemical battery pack, along with control systems (Kuchta, 2022). This process can be time-consuming as well as expensive and most likely unaffordable for the average vehicle owner (Evers, 2023). This research has shown that there are businesses that are able to retrofit hub motors to the undriven wheels, as well as test the feasibility of installing mechanical batteries into the vehicle in place of chemical batteries.

LIB's are commonly found in EV's as the ESS (Annamalai & Amutha Prabha, 2023). A LIB comprises several components: an anode, cathode, separator, electrolyte, and two current collectors (positive and negative) (Minos, 2023). The anode and cathode serve as storage for lithium. The electrolyte facilitates the movement of positively charged lithium ions between the anode and cathode through the separator, generating free electrons in the anode and creating a positive charge at the current collector (Minos, 2023). The electrical current subsequently flows from the current collector, powers a connected device (e.g. EV motor), and returns to the negative current collector (Minos, 2023). The separator plays a crucial role in preventing the flow of electrons within the battery (Minos, 2023). A FES system stores kinetic energy (KE) in a high speed rotating disc about a shaft that is connected to a motor / generator (Mousavi G et al., 2017). FESS has many attractive attributes such as high energy efficiency, fast response times, low maintenance and environmentally, compared to LIB systems (Mousavi G et al., 2017).

Braking is typically accomplished through mechanical methods, most commonly by employing friction brakes. In this process, stationary brake pads are applied against the rotating brake discs located on the driveshaft. This action serves to decelerate or bring the driveshaft to a complete stop (Toh Xiang Wen & Tong Kum Tien, 2018). Heat is the result of the brake pads and rotors coming into contact (Toh Jiang Wen & Tong Kum Tien, 2018). This heat dissipation results in spent energy losses of up to 30% and is not constant throughout the operating velocity ranges (Wang et al., 2021). Regenerative braking can recoup this energy and minimise fuel consumption (Michael, 2018). Regenerative braking won't replace traditional braking, however, it has been proven for the two systems to work in conjunction (Michael, 2018). This brings about further positive aspects such a fuel savings that have come from regenerative stop/start cycles, as well as a reduction in emissions (Lee et al., 2011). This then leads on to the hybrid power-trains. Hybrid power-trains have become very popular in the transport industry due to the lower fuel consumption and emissions (Trajkovic et al., 2013).

2.1 Energy Storage Systems (ESS)

An important distinction for energy densities of batteries is between chemical and mechanical batteries. Energy density describes the capacity to store energy per given unit mass or volume (Borah et al., 2020). The greater the density, the more energy can be stored. Energy density is measured in watt-hours per kilogram. This is not to be confused with power density. The difference between energy density and power density is a measure of watt-hours output per kilogram (Dragonfly Energy, 2022). Energy density of batteries is a topic of great debate. Essentially, the greater the energy density of a battery means the more energy that can be stored in the battery (Ji et al., 2023).

Research into ESS related to the transport industry, has uncovered systems such as chemical, mechanical, hydraulic, and pneumatic ESS. The mainstream form of energy storage within the transport industry are chemical batteries (Chen et al., 2019). Chemical batteries are used in EV's, HEV and plug in hybrid vehicles (PHEV's). The major vehicle manufacturers such as Tesla, Toyota, Nissan and Honda, use lithium-ion (Li-ion) batteries in their EV's (Zhao et al., 2023). Chemical batteries that are found in EVs are made from differing materials. Chemical batteries are prone to a condition called thermal runaway (Chombo & Laoonual, 2020). Thermal runaway occurs when the cells' temperature surpasses a critical point, causing the temperature to increase on its own and catch fire. (Warner, 2019). This can cause the vehicle to catch fire, and have the potential to cause great harm and even death (Dakkoune et al., 2019). Furthermore, thermal runaway can be initiated by impact or physical shock sustained to the battery (Chombo & Laoonual, 2020). This shows that chemical batteries at this point, might not be the safest option to uptake for widespread use, hence the reason for conducting research into other feasible ESS options.

The flywheel is an old form of energy storage that predates the automobile (Hedlund et al., 2015). A mechanical battery is a flywheel that is held in place by an axle and is spun around a central point of the axle. When the flywheel is spun up to very high revolutions per minute (RPM), the device becomes a storage reservoir for kinetic energy (Mahmoud et al., 2020). A mass rotating at high rpm is susceptible to rotor instability (Amrr et al., 2022).

This would be applicable to the flywheel as it will be spinning, fluctuating between low and high rpm. Furthermore, the fluctuation in rpm causes further unwanted vibration in the system (Iskakov et al., 2022). Placing the FESS within a gyroscope might aid in the elimination of vibration. The idea within this project is to use a BERS to “charge” the FESS. When the requirement arises for the charge to be released back into electric motors driving the wheels, the flywheel attached to the generator will reverse polarity and the energy will be sent to the driving motors. A FESS could provide power similar to a super capacitor, when installed in such a configuration (Hedlund et al., 2015).

FES systems have many positive attributes over chemical batteries (Emerging Trends in Energy Storage Systems and Industrial Applications, 2023). Specifically, FES systems have a significantly longer serviceable life than chemical batteries (Li & Palazzolo, 2022; Alami, 2012). This is due to the properties of the materials that are used to manufacture them (Hedlund et al., 2015). The average EV battery can be charged up to 2000 times before the degradation process of the battery begins (Alami, 2012). Battery degradation occurs when the battery loses it ability to store and deliver energy (Deng et al., 2023). When the capacity of an EV battery drops below 80% of its original storage capacity, it is said to have reached its end of life stage (Deng et al., 2023). A flywheel battery can be charged over 1 million times (Alami, 2012). The dangers of a chemical battery lie within the issue of thermal runaway. Thermal runaway occurs when an exothermic reaction occurs within cell/s of the battery and mass amounts of heat is generated (Feng et al., 2018). This often results in the material surrounding the cells in the battery to catch fire (Bruchhausen et al., 2023). Practically, these batteries carry a risk of catching fire which is a hazard risk (Cui et al., 2022). Furthermore, the FES system would weigh less than a traditional chemical battery (Torell, 2020). This could lead to a more energy efficient vehicle due to less mass being propelled.

It is understood that gyroscopic action may cause issues with a FESS, due to a mass rotating about an axis (Gyroscopic motion, 2014). This occurs due to the conservation of angular momentum (Nave, 2009). Gyroscopic motion can be described as a rotating objects' tendency to maintain the orientation about the axis of its orientation (Gyroscopic motion, 2014). An example many people can relate this subject to, is a spinning top. The spinning top will resist change about its axis of rotation. If change about the axis occurs, the object's angular momentum will change (Gyroscopic, motion 2014).

There is evidence that a mechanical battery could be used in an automotive application. Kinetic energy increases quadratically when the radius and angular velocity increases (Hedlund et al., 2015). The equation below shows this:

$E = \frac{1}{2} I \Delta\omega^2$

E is energy, I is the moment of inertia around the axis of rotation, and delta omega is the change in angular velocity.

Chemical batteries are used in a variety of applications. A chemical battery is designed to harness energy from a chemical reaction, with the ions involved to freely move and interact, concurrently compelling electrons to traverse an external circuit for energy transfer or absorption during battery charging (Folkson & Sapsford, 2022). The chemical battery has proven to be dangerous as well as the cause for the majority of incidents involving EV's

(Hu,.et al. 2021). In this instance, a mechanical battery (flywheel battery) stores energy in the form of mechanical energy (Burheim, 2018). The mechanical energy is converted to electrical energy through an electric motor that acts as a generator when it is required to discharge the stored energy (Burheim, 2018).

The cost to manufacture a FESS might come at a reasonable cost. As an example, the cost of stainless steel is $5 per kilogram (Steelplates, 2023).The material would have to be suitable to the high stresses seen from rotational forces(Bamisile et al., 2023). From this, it is estimated that the material cost per stored joule would be $2.50 (Barnett, 2020). Converting this to 1kWh, it is said that this would result in a cost of $72 per kWh (Barnett, 2020). Whereas lithium-ion batteries cost $151 per kWh (Henze, 2022). Assuming that a flywheel battery is as efficient as a chemical battery, the cost per kWh is significantly less. The average EV battery has an energy density of 270Wh/kg (Lombardo, 2023). The energy density of a flywheel is based on the material properties of the flywheel as well as the maximum angular velocity of the system (Bamisile et al., 2023).

Pneumatic systems have been used in the transport industry for decades. Examples of pneumatic systems used in the transport industry include braking systems, suspension systems and actuators (Bravo et al., 2018). Pneumatic Regenerative Engine Braking (PREB) is another form of regenerative energy. It converts spent energy from a fossil fuelled system. This energy is rerouted back into the drive train when required (Lee et al., 2011).Pneumatic systems are not explored in this thesis however, it could be an option to look into as a part of the future research into increasing the efficiency of fossil fueled vehicles through regenerative braking.

For the purpose of this thesis, a FESS will be compared to a LIB. Chemical batteries are found in all EV's, PHEV's and HEV's. Chemical batteries such as LIB's are the most commonly used battery hence, comparing a FESS with something that is the main ESS in the automotive industry. A comparison between the FESS and LIB allows for a comparison to the current gold standard, in order to understand whether it is feasible to move forward with the FESS in an automotive application.

2.2 Electric Motors and Generators

Regenerative braking is a method to recoup spent rotational energy (Michael, 2018). If the voltage at the power source is greater than the back electromotive force (EMF), then the electric motor will act as a motor. If the EMF is greater than the battery voltage, then it acts as a generator. Figure 1 diagrammatically explains how regenerative braking works.

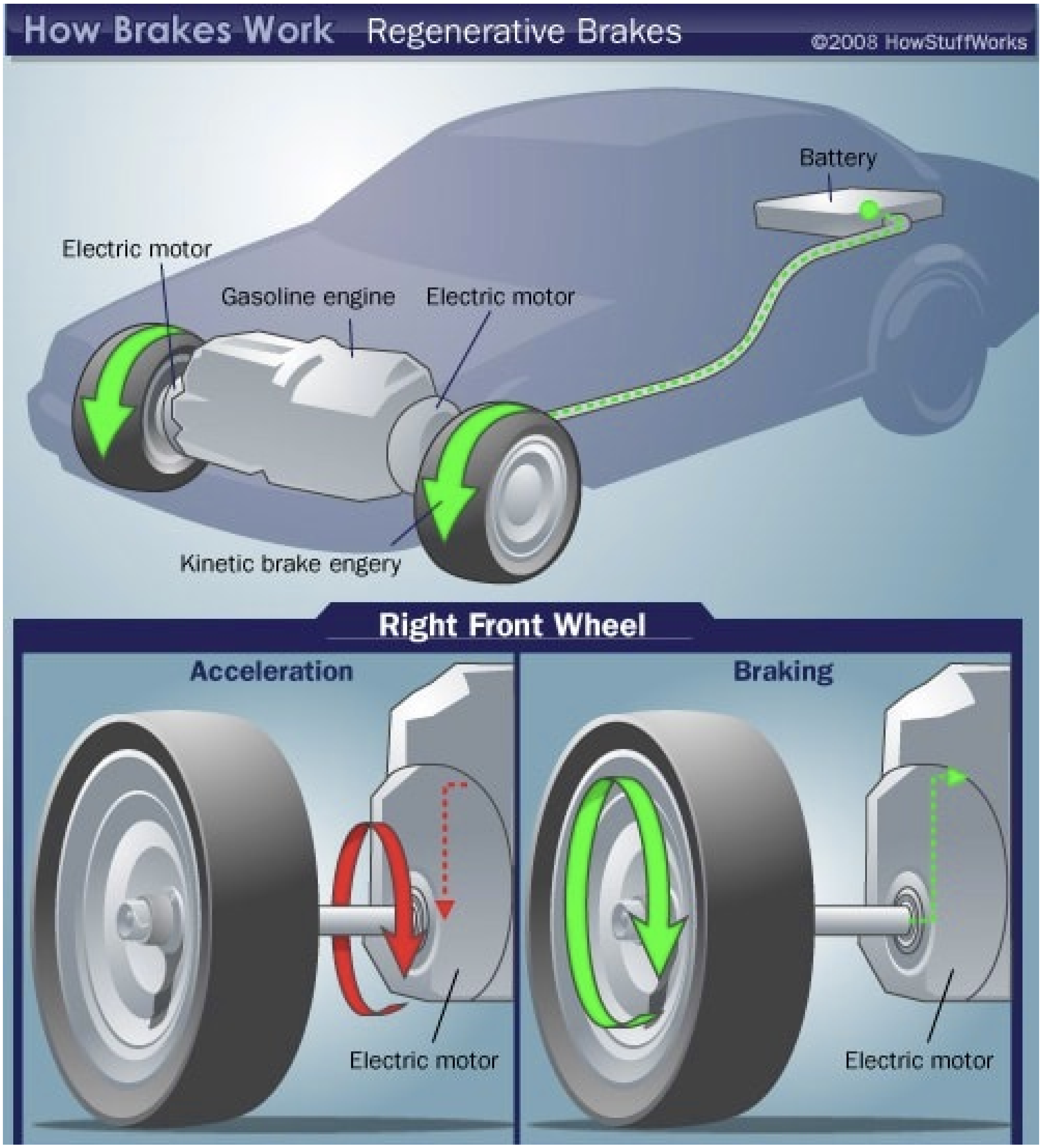


Figure 1: Regenerative Braking process, (Michael, 2018)

Research has shown a multitude of options to manage the voltage fluctuations produced by the changing rpm of the flywheel and generator / in-wheel motor (Tang, 2019). It is crucial that the electrical control systems are suited to the intended use and there are large fluctuation in voltage due to sudden changes in load (Hamidah et al., 2023). Options to manage and control the electrical system include automatic voltage regulators (AVR) and a pulse width modulator (PWM). However, it must be recognised that complete control of energy management and regeneration from regenerative braking is not attainable (Hamada & Orhan, 2022). This is due to the energy loss of friction, and heat dissipated during the braking process (Hamada & Orhan, 2022). This ties back into the issue of increasing efficiency of the system through electric components such as motor/generators, ESS and voltage controllers.

Electric motors are used to convert electrical energy into mechanical energy (Boldea, 2017). Furthermore, electric motors can also be used as generators to convert mechanical energy into electrical energy (Boldea, 2017). Electric motors and generators are available in Direct Current (DC) and Alternating Current (AC) configurations. The AC electric motors are also known as induction motors, and they are mainly used in industrial applications (Chuang et al., 2019). Brushed and Brushless DC (BLDC) motors can be used as generators (Kafader, 2019). In this thesis, the electrical motor / generator that shall be used will be a BLDC. Brushed DC motors require a mechanical system in order to transfer and control current. This mechanical component is known as a brush (Power Electric, 2020). This component is known to wear out hence, being a point of failure within brushed DC motors (Power Electric, 2020). DC motors have been chosen as the motor / generator due to their versatility and capability to exploit large quantities of energy (Reato et al., 2023). Furthermore, BLDC motors are said to be more energy efficient than brushed motors (Purwadi et al., 2013). BLDC motors can operate at excess of 1000rpm whether there is a load applied or not (Purwadi et al., 2013). Further positive attributes of a BLDC motor is that it can change accelerate very quickly as well as change direction of rotation very quickly (Purwadi et al., 2013).

2.3 Mathematical Background

MATLAB will be used to conduct calculations for this thesis. Furthermore, the outputs provided by MATLAB will aid in the decision making process and be used in the results and discussion section of this thesis. MATLAB is a numeric and program computing software suite used by engineers to model and analyse data (MathWorks, 2023). As an example, MATLAB will be used to calculate the gyroscopic action caused by the flywheel increasing and decreasing in RPM. Further to this, MATLAB will be used to manipulate the values mass of the flywheels, diameters and RPM.The equations used in this thesis can be found in the appendix section and will be explored in the discussion section as well as the appendix section.

2.4 Context of the Problem

Emissions from passenger and commercial vehicles are responsible for almost a quarter of the GHG emissions worldwide (Xia et al., 2015). These emissions are a result of burning fossil fuels to generate propulsion. The global transport industry accounts for 20% of CO_2 emissions (Corby, 2021). CO_2 emissions that are generated from the transport industry are measured in metric tonnes, with the average fossil fuelled passenger car generating about 4.6 metric tonnes of CO_2 per year (Corby, 2021). Meanwhile, the end production date of fossil fuelled vehicles is looming due to their GHG emissions. Governments have been the main driving force behind EV adoption rather than consumer demand like mainstream media portrays (Yergin, 2021). An example of such a driving force is President Joe Biden stating that 50% of all new vehicles sales should be EV's (Yergin, 2021). In Australia, there are programs in place from both government and private enterprises that are encouraging people to change their travel habits to become more environmentally conscious and friendly (Xia et al., 2015). The government of the Australian Capital Territory (ACT) is offering the people stamp duty exemptions, two years free EV registration and zero interest loans over a period of up to ten years (Access Canberra, 2023).

However, EV's have many issues that need to be addressed including manufacturing and recycling of EV's, HEV, PHEV's and ICEV's. Internal combustion engine (ICE) vehicles have a cleaner production process, yet EV's have a cleaner and less environmentally damaging operational life (Puig-Samper Naranjo et al., 2021). The argument of energy requirements to manufacture and dispose of the EV's is also greater than the ICE (Salguero, 2022). Specifically, the mining of materials for batteries is known to be a significant task and not to mention the damage it causes to the natural environment (Chen et al., 2023). Furthermore, the supply chains of lithium to manufacture the batteries and safely transport the batteries, as well as the end of life (EOL) process related to EV's leaves room for improvement (Winton, 2021). The recycling process associated with these batteries is known to be environmentally damaging (Chen et al., 2023). This means that a solution that can improve the fossil fuel systems to become more efficient should be further explored as a potential alternative.

Fossil fuelled vehicles are still the preferred option to EV (MER, 2023). Predictions state that fossil fuelled vehicles will remain due to their longevity and capability to haul large and heavy loads (Winton, 2021). Due to the energy density of fossil fuels, there is a belief that bulk transport operations will still require the use of fossil fuels until at least 2040 (Wang et al., 2021). Another major drawback for EV's is their limited range as well as the time it takes to charge the battery (Rashid & Danial, 2017). The need for this in Australia is clear, given the vast land mass that needs to be navigated in order to maintain supply chains. Due to the large distances from A to B, the EV programs won't always suit the Australian road (Taylor & Ampt, 2003). The average private vehicle in Australia travels 36 kilometres per day (Mcgrath, 2019). Current EV's have an average range of 320 kilometres (Finnerty, 2023), whereas the average internal combustion vehicle (ICEV) has a range of 665 kilometres (Bhutada, 2022). The range of the average ICEV could be extended as well as emissions could be minimised through retrofitting hub motors in conjunction with either a chemical, mechanical, hydraulic or pneumatic energy storage system (Kaleg et al., 2015). Simulations of retrofitting electric hub motors to ICEV's has shown the potential for fuel consumption decreases as much as 25% (Zulkifli, Mohd, Maharun, Saad, & Aziz, 2012). Furthermore, it has been postulated that retrofitting hub motors may decrease harmful emissions (Alcoberro et al., 2021). This could be a good alternative to the EV market, which is growing rapidly worldwide, with sales growth rates year-on-year around 30% (IEA,2023). This is why retrofitting electric motors in conjunction with short range batteries, to fossil fuelled vehicles is a great alternative. This alternative may allow for less fuel to be used, along with less energy being wasted through recouping energy through regenerative braking.

Cost and legislation are also a big motivation for this project. Batteries are becoming cheaper, but they are still too expensive for the general population to afford. The target market for HEV's, EV's and PHEVs are high income earners (Huang et al., 2021), essentially, minimising the reach of this product. Widespread adoption will occur when the purchase price of the vehicle drops. Much like when the cost of manufacturing vehicles had decreased with Ford's innovative production line (Matei, 2017). Other practical issues facing EV owners include finding a charging station (The Pros and Cons of Electric Cars (EVs) — Ocean Crest Chevrolet Buick GMC, 2022). Owners can charge their cars from home, however, this is a challenge for some owners who do not have a garage or power point in which they can use to charge their EV. Further issues for owners' include finding fast chargers, suitable charger locations and price per kWh of the charge per location (Visaria et al., 2022). The location may differ from home, to public locations, to office charging points. As EV's become more popular, the demand for charging points will amplify this issue (Aguilar and Groß, 2022). This may lead to "bottlenecks" at charging stations causing more issues for the EV owner.

In addition to these concerns, the issue has been raised that the electricity grid will not be able to handle the load of daily household electrical requirements along with the new load of EV's (Can the power grid handle the transition to electric cars? — IPWEA, 2022; Faaji, 2006). The energy sector is also undergoing a change in energy source from fossil fuels to renewable energies (Li et al., 2020). It is thought that expanding on the current green energy options available, is key to future proofing requirements and aid in accommodating the demand on the energy sector (Aguilar and Groß, 2022). HEV's could be a solution to this issue. HEV's do not solely rely on electrical power from the power grid. Hybridisation of fossil fuelled vehicles may promote more people to adopt the green energy resource lifestyle as well as aid in the overall transition to renewable energy sources (Mariani et al., 2022). This follows on to the feasibility of retrofitting in-wheel motors along with mechanical batteries into existing fossil fuelled vehicles.

2.5 Motivation for the Project

The main motivation for this project is to increase the efficiency of fossil fuelled vehicles. As a consequence in a practical setting, it could have the ability to improve on-road transport to be more environmentally friendly, as well as a safer mode of travel. Governments and corporations are on the path to minimising GHG emissions in the attempt to leaving a better future for those to come, which is a vital category of Corporate Social Responsibility (He, Jiang, & Hu, 2023). Providing a solution to minimise GHG emissions from existing fossil fuelled vehicles will aid in keeping the people and the environment healthy (Jain et al., 2023). The consensus within society today is to be more conscious of the planet's waste production (Guillard, 2018). Thus, this is driving the force behind how we as a collective, might be able to better use our resources to minimise our carbon footprint (Walzberg, Sethuraman, Ghosh, Uekert, & Carpenter, 2023). Furthermore, a mechanical battery is not limited to the amount of energy storage capacity like the chemical batteries (Hebner et al., 2002). It is worthwhile investigating the efficiency and viability of the mechanical battery compared to the chemical battery.

Further barriers to entry of ownership of EV's and HEV are other factors that are driving the research into this topic. The purchase price of an EV is almost 3 times more than the equivalent ICEV (Alcoberro et al., 2021). The majority of the cost of EV conversion lies within the battery, depending on type and capacity (Kaleg et al., 2015). Research into retrofitting electric motors to existing fossil fuelled vehicles could aid in the uptake of EV's. This brings further validity to undertake research into retrofitting electric motors to existing fossil fuelled vehicles. The life cycle of existing ICE vehicles could be extended, thus minimising waste as well as giving older vehicles a newer lease on life (Li, Liu, Chen, Huang, & Ju, 2022).

2.6 Consequences and Ethics

Adoption of EV's is said to be one of the most important aspects of green technologies' adoption (Qian & Yin, 2017). Energy transitions are the driving forces of green initiatives. Our modern lives are dependent on the transport industry which is one of the largest contributors of GHG emissions. Hence, the research into the multitude of options that may allow for a greener future (Herrington, 2021). The transition to green / renewable may have an impact, not just for energy production, but is said to have the potential to affect economic, social, and political sectors (Miller, 2014). Furthermore, the transition to green energy has generated more jobs (Bowen, 2012), which relate to the economic and social impacts that this shift causes. The most concerning issue regarding job creation, is that third world countries are inundated with e-waste and proper procedures are not in place to mitigate harm to persons and the environment (Sovacool et al., 2020). E-waste is known to have an array of toxic materials. These waste materials must be handled by trained persons to ensure the materials are safely recycled or appropriately disposed (Sthiannopkao & Wong, 2013). An alternative system that could potentially minimise these ethical dilemmas needs to be explored further, hence underlying te importance of this thesis.

3 Methodology

3.1 Methods

This thesis explored in the background chapter the relevant information pertaining to this thesis, having explored the topics of regenerative braking, ESS and current social trends surrounding the green vehicle movement. Based on this information, decisions were made on the technologies that would be utilised in this thesis. Firstly, once there was a general understanding of renewables in the automotive industry, further research was conducted surrounding ESS. This thesis focused upon the comparison of a FESS versus a LIB, as to which battery would be more efficient. These batteries were used to investigate stored energy from a BERS, and then reroute that energy to power the in-wheel electric motors. Essentially, it was chosen on the basis to allow the exploration and comparison of technologies and looking further into this largely unexplored area to find untapped advantages. It will be shown that brushless and brushed DC motors can be used as a generator (Kedia, 2021). Research into off the shelf products that are available as well as best implementation practice was conducted in the background. Due to the simplicity of BLDC motors and their versatility, they have been chosen for both the in-wheel motor and the motor/generator that the flywheel shall be attached to for this thesis.

The data will be modelled using MATLAB. The reasoning for using MATLAB in this thesis is to use it to model information and come to suitable conclusions regarding the feasibility of this thesis. The results for this thesis will be gained from analysing mathematical modelling. The formulae and equations used in this thesis are presented in the relevant sections as well as the appendix section. This data will come from assumptions based on an array of factors that are outlined below.

3.2 Assumptions

The calculations used in this thesis were conducted using information from an array of sources which underlines the assumptions. These assumptions are as follows:

1. The information from these articles are assumed as correct and true, and have been used to carry-out relevant calculations for this dissertation.

2. There are several factors that affect grip and coefficient of friction for car tyres. Examples of factors that affect friction would be the temperature of the tyre, differing compounds within the tyre and angular velocity (Salehi et al., 2020). This affects the research at this point as these factors are not included in the calculations

3. A modern passenger vehicle, that is in roadworthy condition, is capable of applying its brakes to affect deceleration of $7m/s^2$ (Queensland Government, 2016). This value is would be used in emergency braking. A comfortable deceleration rate for most passengers in a vehicle is 2 to 3 $\mathrm{m/s^2}$ (meters per second squared) (Keys & Ayers, 2012) .

4. The average vehicle mass of 2050kg (Craft, 2023).

5. The efficiency of the direct current (DC) electric motors has been assumed to be at 95% (Kaleg et al., 2015).

6. Wind resistance is negligible.

7. Calculations have been carries out using SI units. Where required, numerical values were converted to SI units.

A free body diagram (FBD) of a single wheel shown below in the figure 1. F_{rr} is the rolling resistance force, $\boldsymbol{T}$ is the transmitted wheel torque, ω_w is the rotational velocity of the wheel, r_w is the radius of the wheel, the linear velocity of the wheel as V_w. This free body diagram has been included to give the reader a greater understanding of the problem. This diagram will be used in the method to aid in angular velocity calculations.

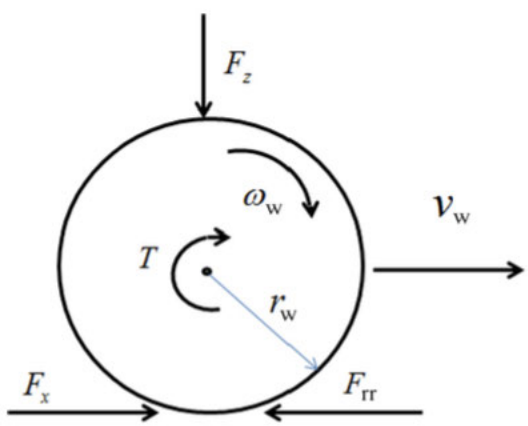


Figure 2: Free body diagram of a wheel (Khaleghian et al., 2017)

Figure 3: Above is an example of an in-wheel-hub motor would be mounted as shown above (Elaphe, 2023). This is a possible motor / generator that could be used to verify the feasibility of this thesis.

Initially, it was thought that higher average speeds would be needed in order to capture usable energy. Initial velocity of 10 m/s was assumed, as this wouldn't require a large flywheel. The issue related to this is that a larger flywheel will take up more space in the vehicle as well as take up useable carrying load of the vehicle.Calculations relating to gyroscopic motion will be discussed in the results and the discussion sections of this thesis. Further to this, calculations relating to hoop stress of the flywheel configurations will be done. Comparisons of round trip efficiencies and methods of delivery between a LIB and a FESS will be calculated and discussed.

3.2.1 Vehicle Parameters

Mass: 2050 kg velocity: 0km/h to 60 km/h Efficiency of electrical systems is at 90% Efficiency of FESS is at 85%

3.2.2 Equations

$$\text{Energy Density} = \frac{\text{kWh}}{\text{kg}}$$

$$\text{Energy Density} = \frac{45\text{Wh}}{20\text{kg}}$$

$$\text{Energy Density} = 2.25Wh/kg$$

1. **Convert the initial and final velocities to meters per second (m/s):**
   - Initial velocity: $0\,\text{km/h}$ is equivalent to $0\,\text{m/s}$.
   - Final velocity: $60\,\text{km/h}$ is equivalent to $\frac{60\times1000}{3600}\,\text{m/s}$.
2. **Calculate the change in kinetic energy (Joules):**
   $\Delta KE = \frac{1}{2} \times \text{mass} \times (\text{final velocity}^2 - \text{initial velocity}^2)$
3. **Convert the energy from Joules to kilowatt-hours (kWh):**
   - Use the conversion factor $1\text{ Joule} = 2.77778 \times 10^{-7}\,\text{kWh}$.

1. **Change in Kinetic Energy during Acceleration (Joules):**
   $\Delta KE = \frac{1}{2} \times \text{mass} \times (\text{final velocity}^2 - \text{initial velocity}^2)$
2. **Energy Recovered during Regenerative Braking (kWh):**
   $\text{Recovered Energy (kWh)} = \Delta KE \times \text{Regeneration Efficiency Factor} \times \text{Joules to kWh Conversion Factor}$
3. **Energy Required for Acceleration (kWh):**
   $\text{Energy Required (kWh)} = \Delta KE \times \text{Joules to kWh Conversion Factor}$
4. **Energy Contribution from the Internal Combustion Engine (kWh):**
   $\text{Engine Energy Needed (kWh)} = \text{Energy Required (kWh)} - \text{Recovered Energy (kWh)}$

3.3 Risk Assessment

The risks associated with the project have been described in the USQ Risk Management Document. See the attached appendices section for more information. There is no immediate threat to life or limb during at any phase within this project. Throughout this project, there is no need for personal protective equipment. The reason for this is that there are no power tools being used, no outdoor activities, or travel taking place in the course of this project. If this theoretical thesis was taken further to a practical phase, this would need to be re-evaluated at this time.

4 Results

The results in this thesis have been calculated using MATLAB. The code can be found in the appendix section of this thesis. Many assumptions have been made with regard to realistic values, as outlined in the methodology chapter. Initially, it was thought that higher average speeds would be needed in order to capture usable energy. Initial velocity of 10 m/s was assumed, as this wouldn't require a large flywheel. Furthermore, the changeover time was assumed to be five to fifteen seconds. The first calculation (note 1, appendix) was used to calculate the potential energy storage of a flywheel. The values for the four combinations of flywheels were calculated to be between 0.031 kWh and 0.244 kWh. The values for mass of the flywheel varied from 10kg to 35 kg. The radius of the flywheel varied from 10 centimetres (cm) to 50 cm.

A minimum of 0.079kWh of power is required to accelerate the average vehicle of mass 2050 kilograms (kg) to 60 kilometres per hour (km/h) over 5 seconds. A Kilowatt-hour (kWh) is a measurement of energy over time, while kW is a measurement of power (Artis Energy, 2019). The power required to accelerate the same car under the same parameters is 56.94 kW. To further simplify the calculations, energy loss due to friction and other factors have not been factored into the regenerative braking calculations. The potential energy that could be derived from regenerative braking from the above-mentioned parameters is 0.0554 kWh. The value of 70% for efficiency was chosen as it is a realistic value (Boretti, 2013).

The following calculations were carried out based upon the assumptions mentioned in the methodology chapter of this thesis. There is 31.5 mega joules (MJ) of energy in 1 litre of petrol (Nave, 2014). Taking into account the parameters of the vehicle previously mentioned, basic physics formulae shows that it would take 32 millilitres (ml) of fuel to accelerate the vehicle to 60km/h. This equates to 0.0285 kWh of energy. This figure will differ when all energy loss parameters are considered in the calculation (Li & Palazzolo, 2022).

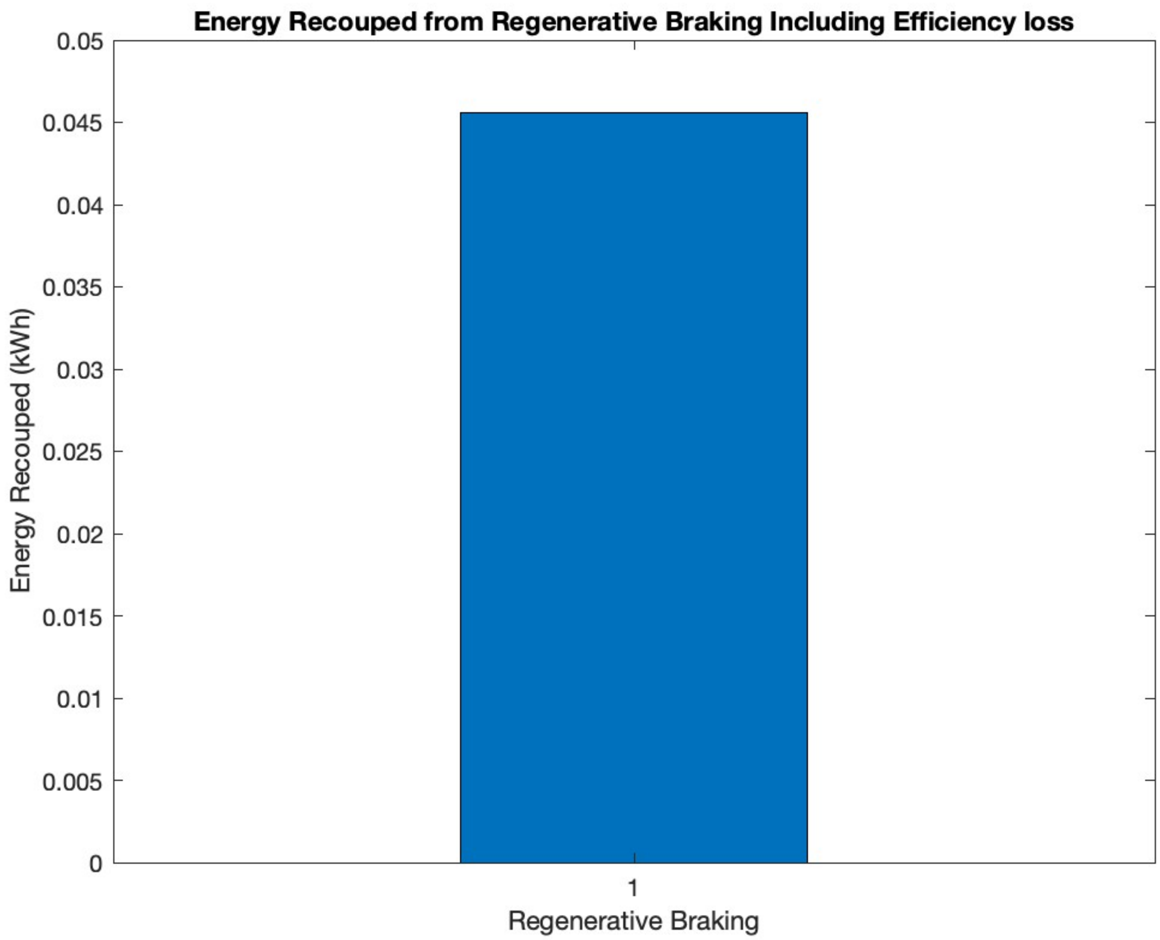


Figure 3: Amount of energy (kWh) that can be recouped through regenerative braking. This was calculated using the kinetic energy equation of a moving object. This value was very important as it gave an insight as to how much energy might be regenerated from one stop start cycle. Figure 3 demonstrates the amount of energy that can be recouped through

regenerative braking from a 2050 kg vehicle that has an initial velocity of 16.67 m/s (meters per second) and comes to a complete stop. It shows that the amount of energy recouped is 0.045kWh. Figure 4 demonstrates that with an increase in radius and mass off the flywheel, the energy storage capacity increases as well as the energy required to generate high RPMs. Meanwhile, Figure 5 shows the amount of energy that is recovered through the regenerative braking process over time. As per the background section of this thesis, the value for efficiency of the system was taken to be 90% in the calculations. Further to this, the above example was modelled from the vehicle parameters mentioned earlier in this thesis (mass of vehicle 2050kg) with the vehicle travelling at 60km/h and then applying the regenerative braking system and slowing the vehicle down to 36 km/h (average metropolis speed). The value was just over 0.07kWh of energy. The graph demonstrates that over time the energy recouped increases.

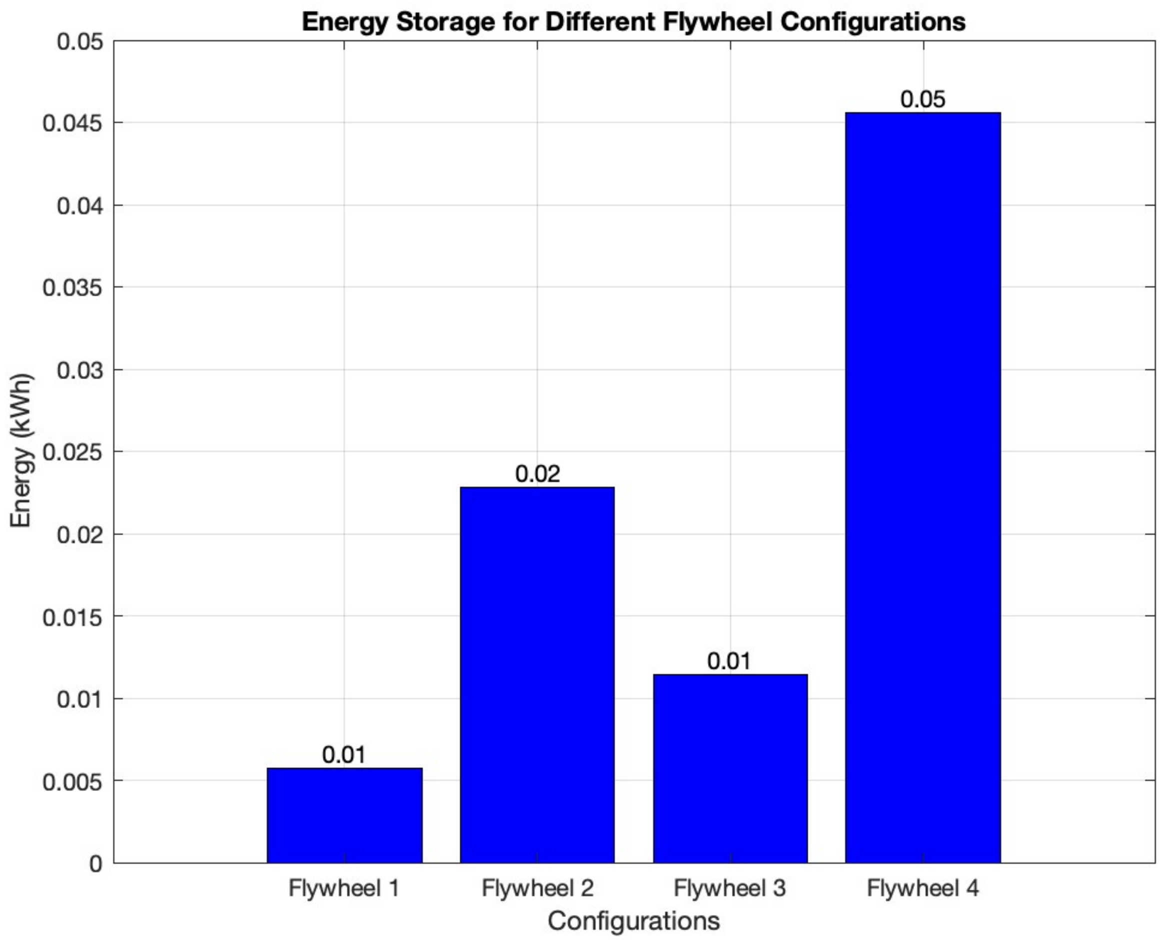


Figure 4: The four different flywheel configurations for energy storage capacity at 8647.68 RPM. This graph shows how mass affects the energy storage capacity of a FESS.

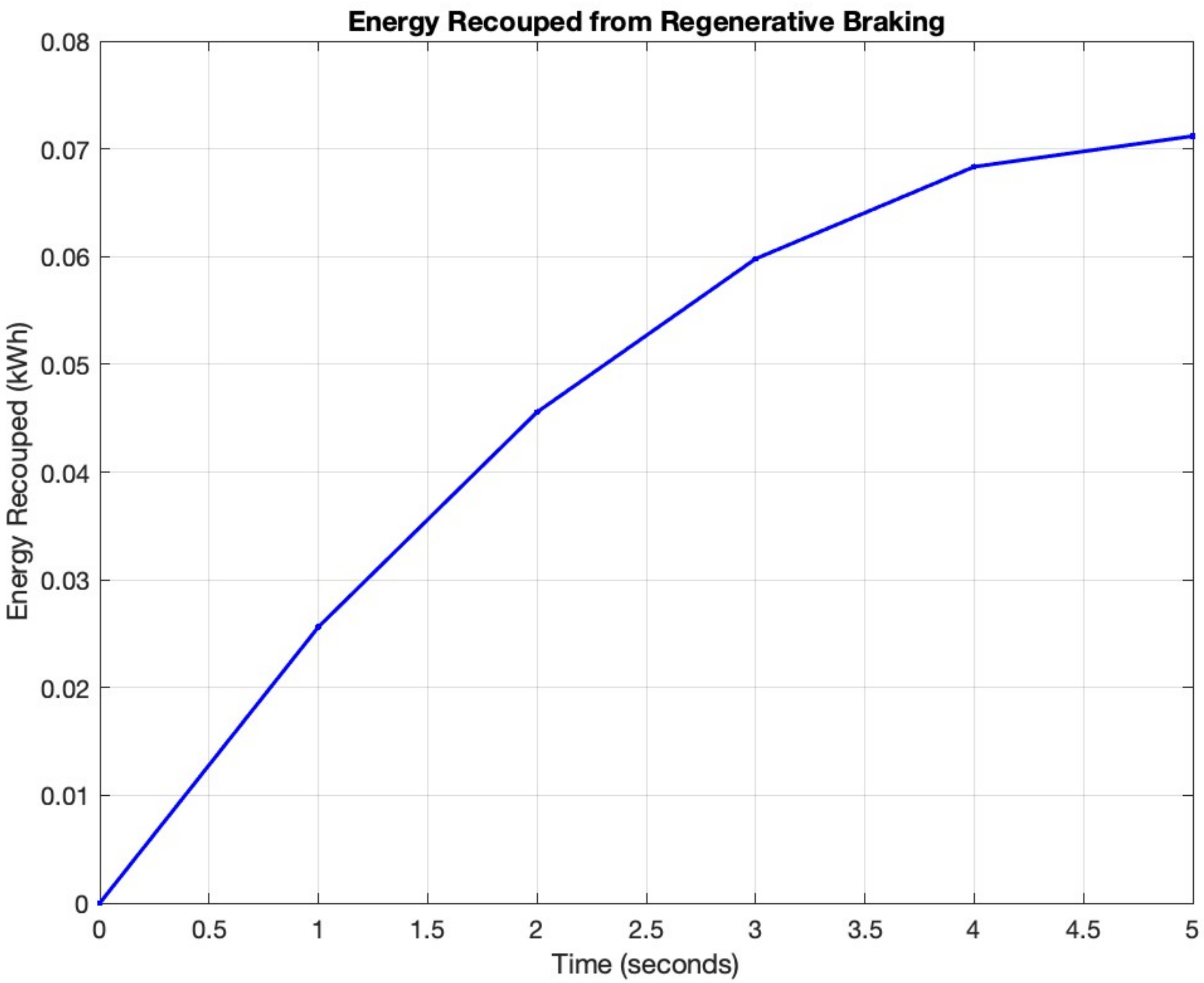


Figure 5: Energy recouped (kWh) over time (seconds).Changes in braking time did not result in a change of energy generated. This graph was generated to show how much energy can be recouped for a given amount of time. This value would not remain constant.

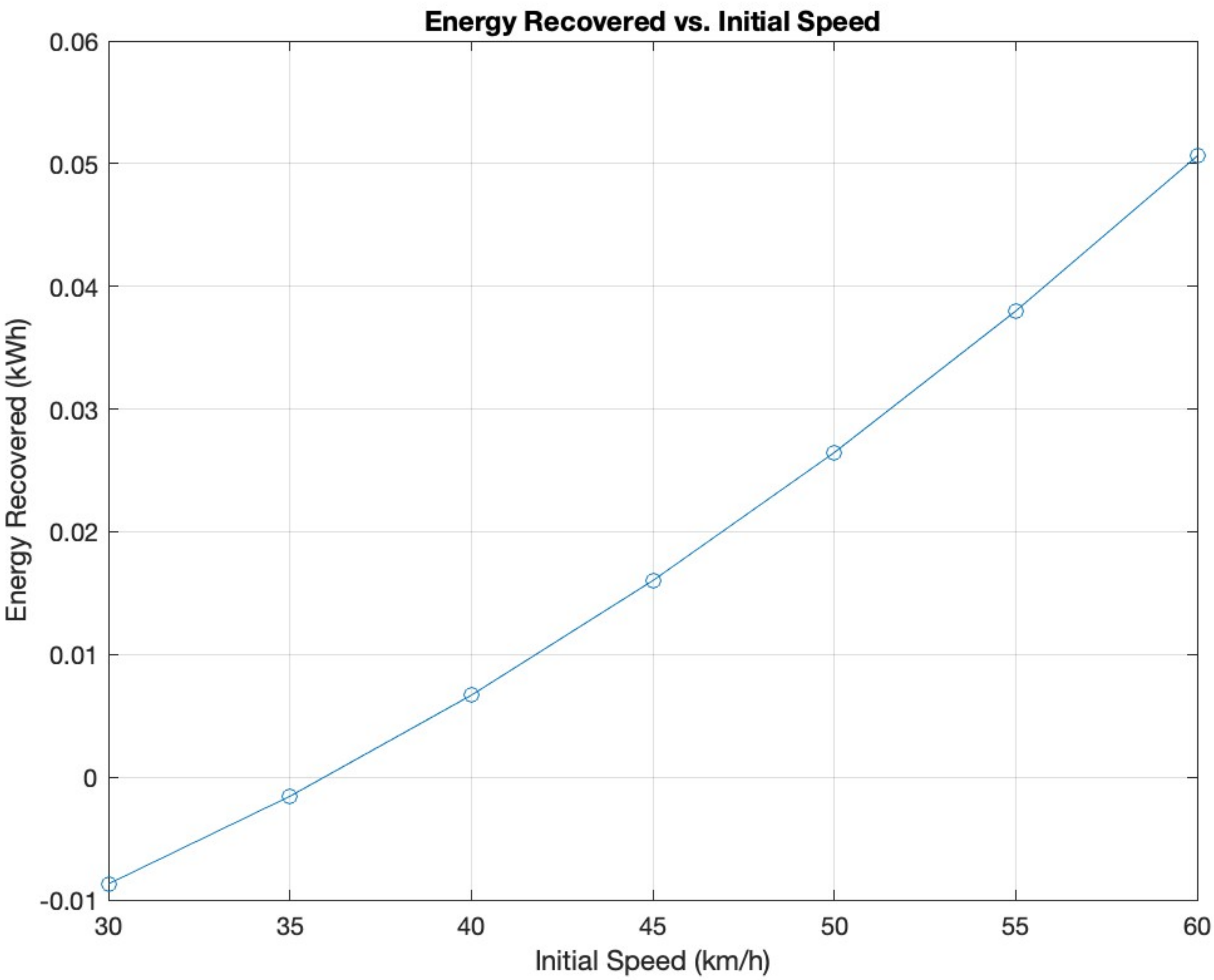


Figure 6: Amount of energy that is recovered (kWh) through the regenerative braking process at certain speeds (Km/h).

The graph above (Figure 6) shows the amount of energy that is recovered through the regenerative braking process at certain speeds. The area under the curve is equal to the amount of energy that is recovered through the regenerative braking process. It demonstrates that with an increase in velocity, there is the potential for more energy to be recouped, however, this means that more energy needs to be spent.

4.1 Flywheel Calculations

All the graphs, calculations and values mentioned or shown in this section were generated using MATLAB.

Four configurations were used to show the trade-offs between mass, radius and rpm.

Flywheel 1: The mass of the flywheel is 10 kg with a radius of 0.1 m.

Flywheel 2: The mass of the flywheel is 10 kg with a radius of 0.2 m.

Flywheel 3: The mass of the flywheel is 20 kg with a radius of 0.1 m.

Flywheel 4: The mass of the flywheel is 20 kg with a radius of 0.2 m.

4.1.1 Energy storage

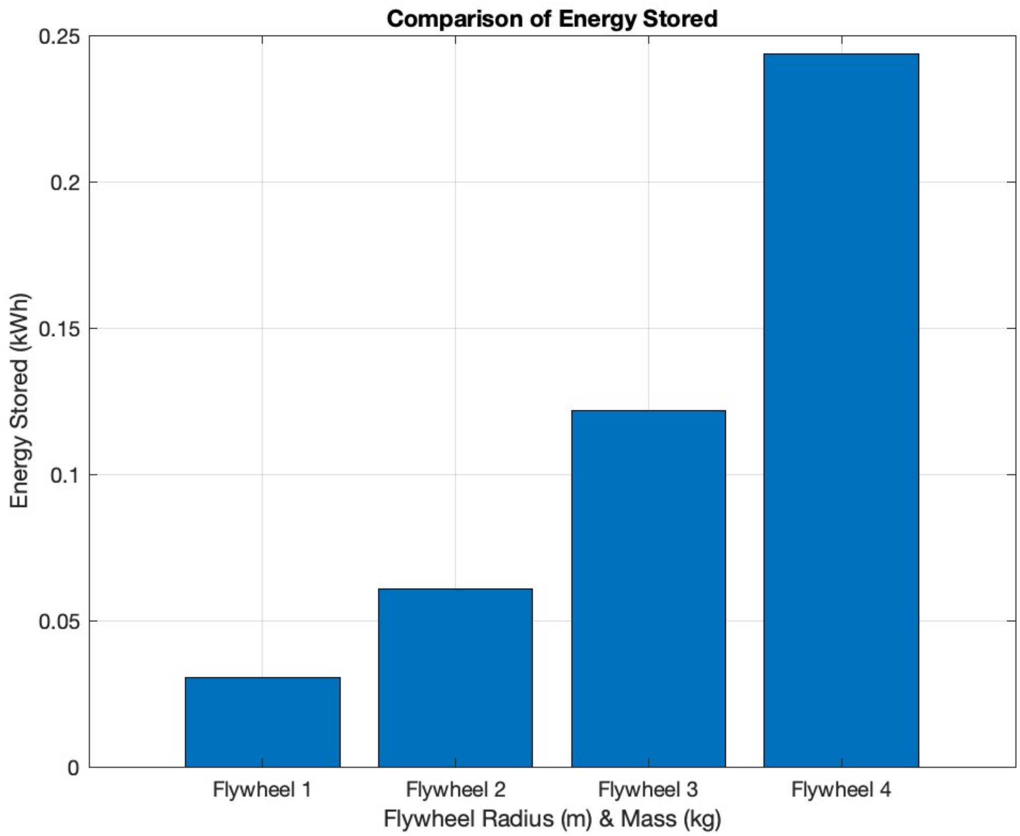


Figure 7: Energy storage (kWh) for each of the four configurations of flywheels.

Figure 7 explored the difference in the amount of energy that can be stored between the four configurations of flywheels. This shows that with an increase in mass and radius, the more energy that can be stored effectively. Likewise, Table 4 explored this in tabulated data. It showed that a higher mass has a bigger impact upon storage than radius.

Table 4: Mass (Kg) and radius (m) variables affect energy stored (kWh)

Flywheel	Mass (kg)	Radius (m)	Energy Stored (kWh)
Flywheel 1	10	0.1	0.030
Flywheel 2	10	0.2	0.061
Flywheel 3	20	0.1	0.122
Flywheel 4	20	0.2	0.244

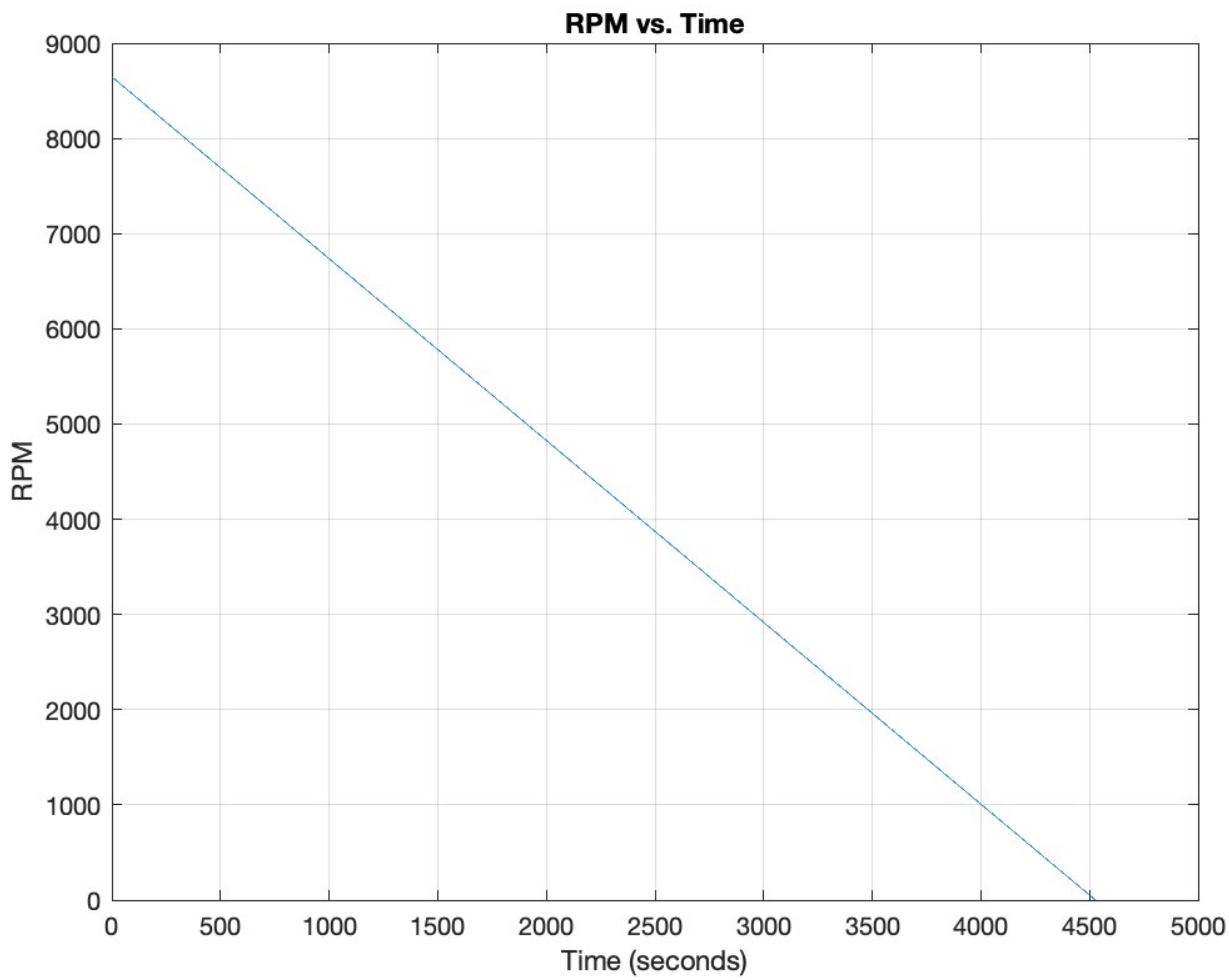


Figure 8: Maximum RPM of flywheel four when charged with the energy recouped from regenerative braking over time (seconds)

Figure 8 explored the maximum rpm of flywheel four when it is charged with the energy recouped from regenerative braking. If the flywheel is not charged any further, it will continue to spin for 75 minutes. It will reach zero kWh after approximately 75 minutes. Figure 9 explored the amount of energy in joules stored in the flywheel being released over time. It showed that RPM decreased over time.

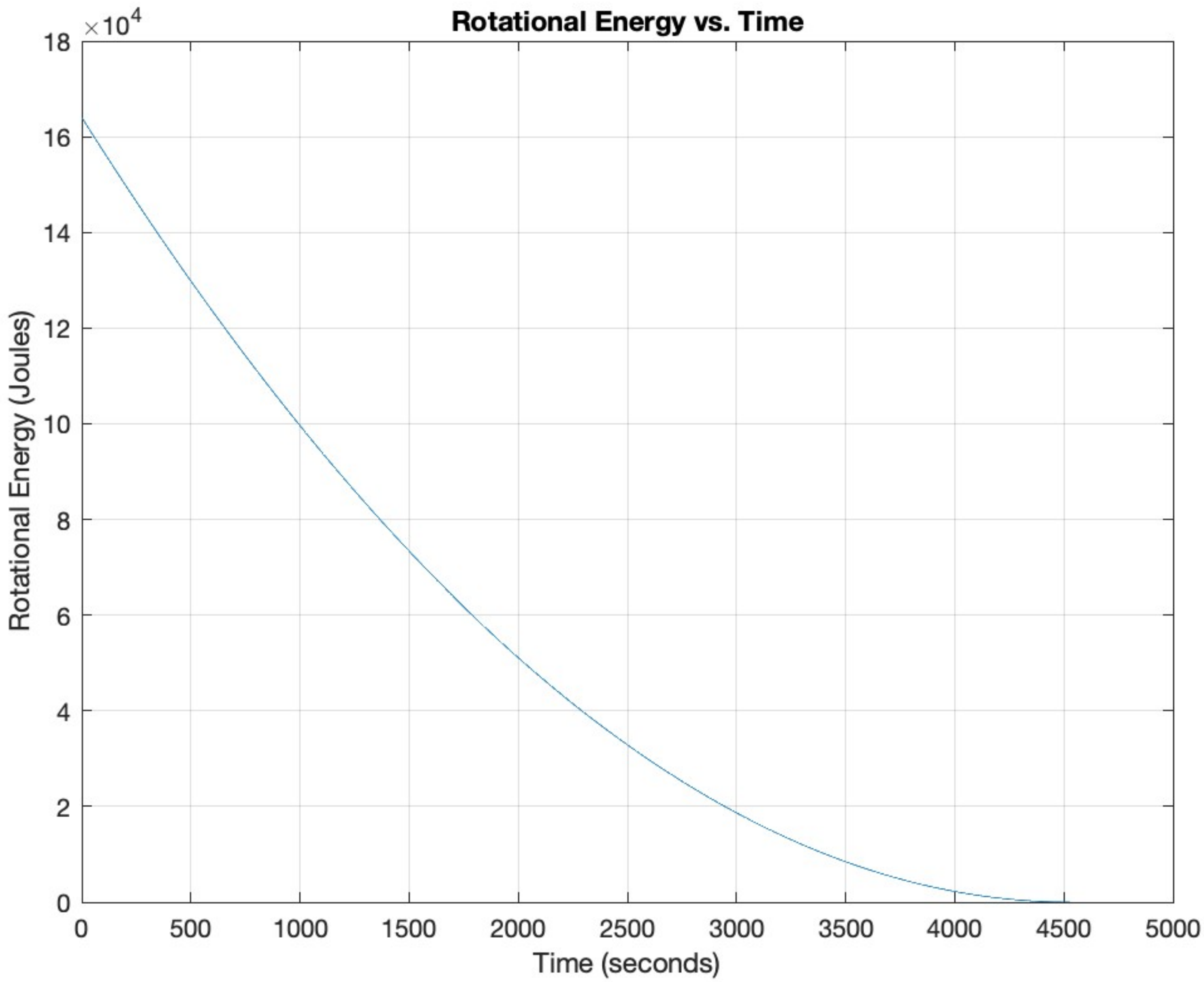


Figure 9: Amount of energy in joules stored in the flywheel being released over time (seconds).

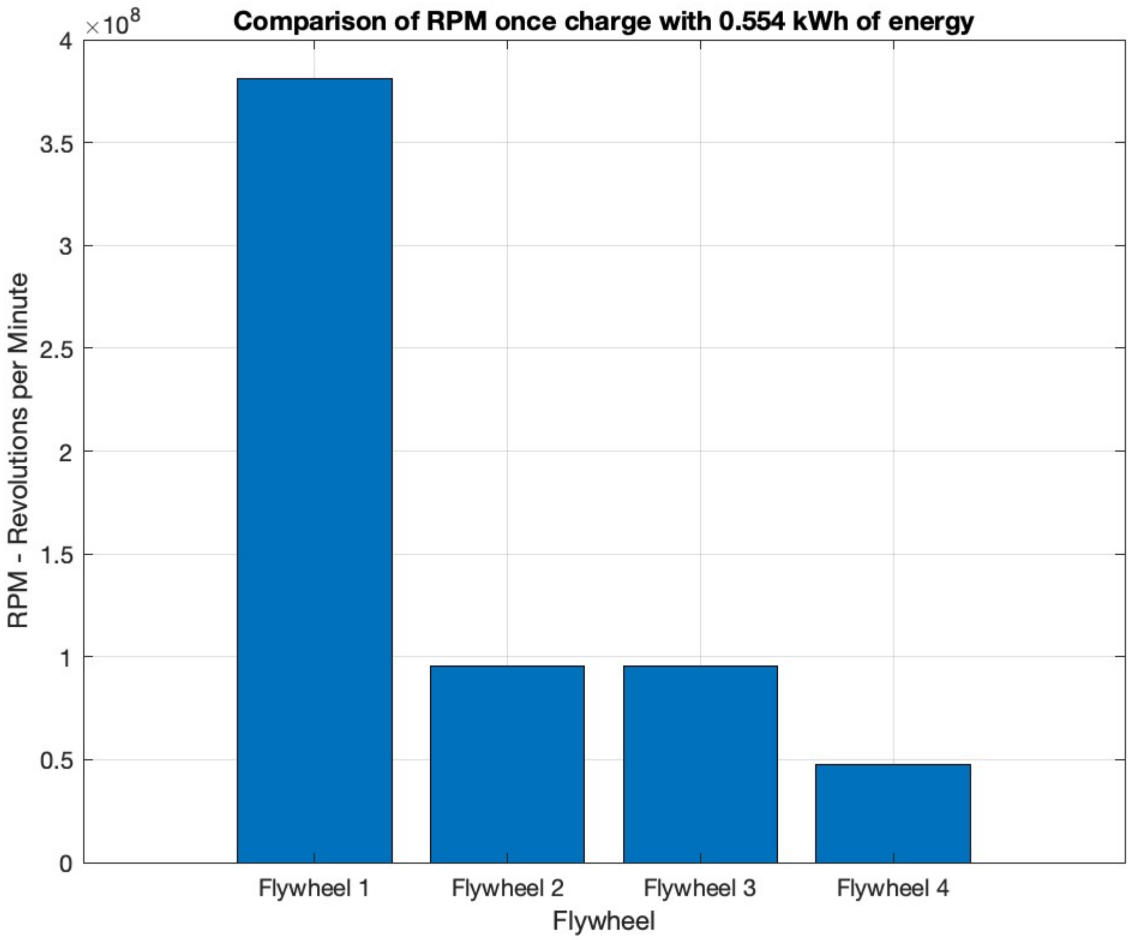


Figure 10: Rpm of the four different flywheel combinations when charged with 0.0554 kWh of energy from the regenerative braking process.

Figure 10 shows the rpm of the four different flywheel combinations when charged with 0.0554 kWh of energy from the regenerative braking process. Flywheel one reached the highest rpm as it has the least mass.

4.1.2 Stresses and Forces

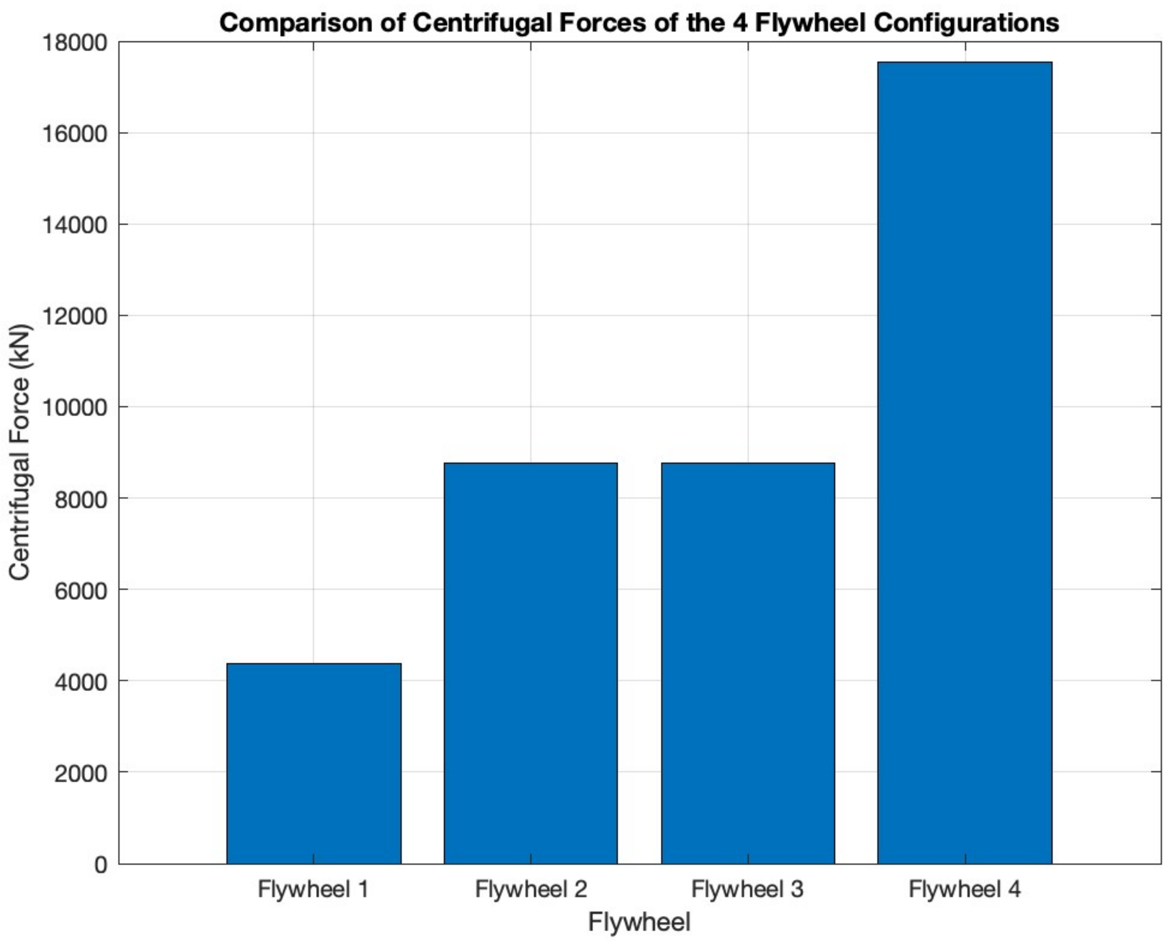


Figure 11: Difference in centrifugal forces (kN) of the four different configurations of the flywheels.

Figure 11 shows the difference in centrifugal forces of the four different configurations of the flywheels. Flywheel four has the greatest centrifugal force as it has the greatest mass out of the four configurations of flywheels. Another point of interest is that centrifugal forces decrease as the radius of the disc increases , yet flywheel four, which has the largest radius has the greatest centrifugal force. This shows that it is indeed true that both mass and radius of the flywheel affect the centrifugal forces. The reason for conducting these calculations was to have a base to start from for the future research in positioning the system in a vehicle if this project were to continue.

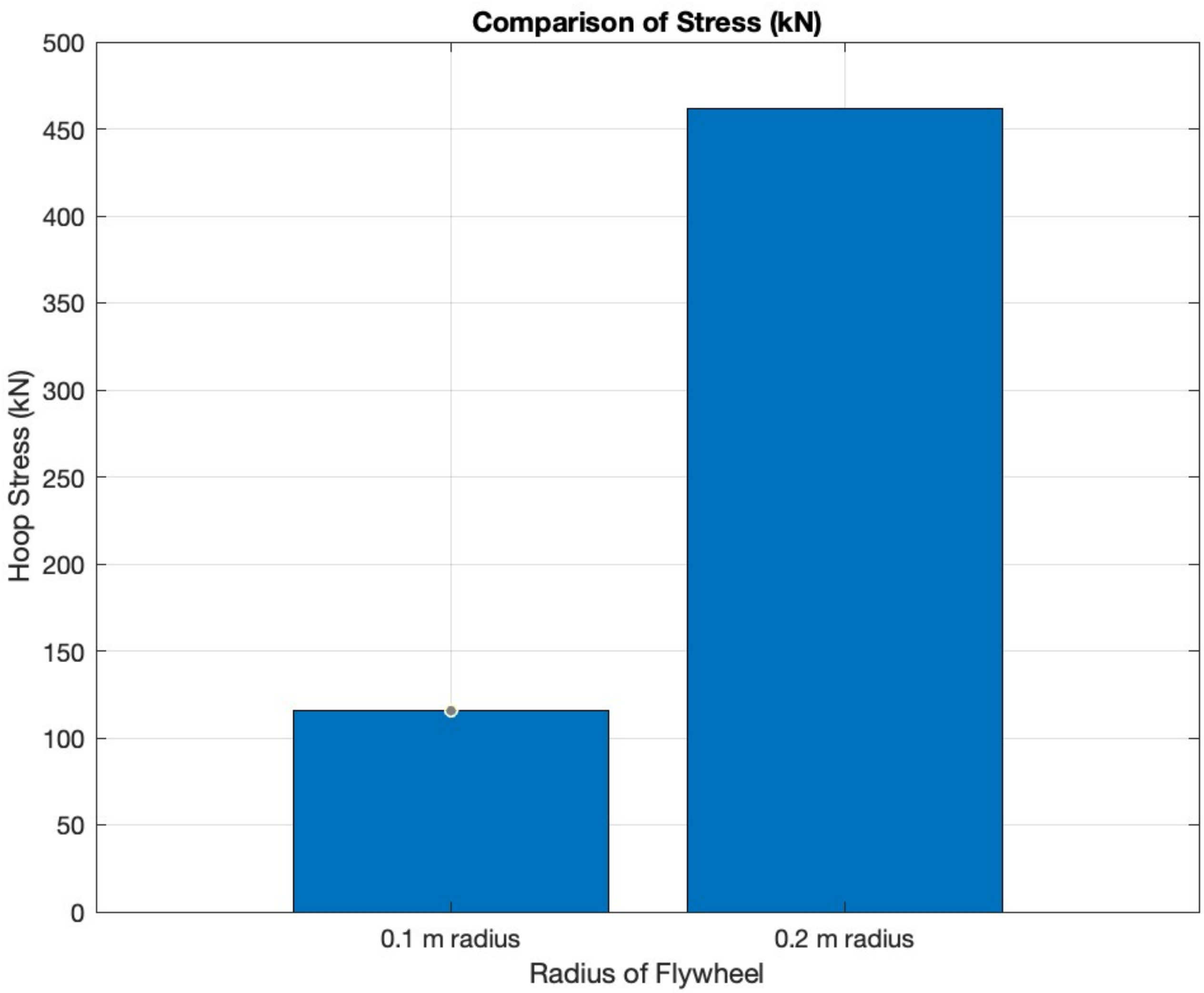
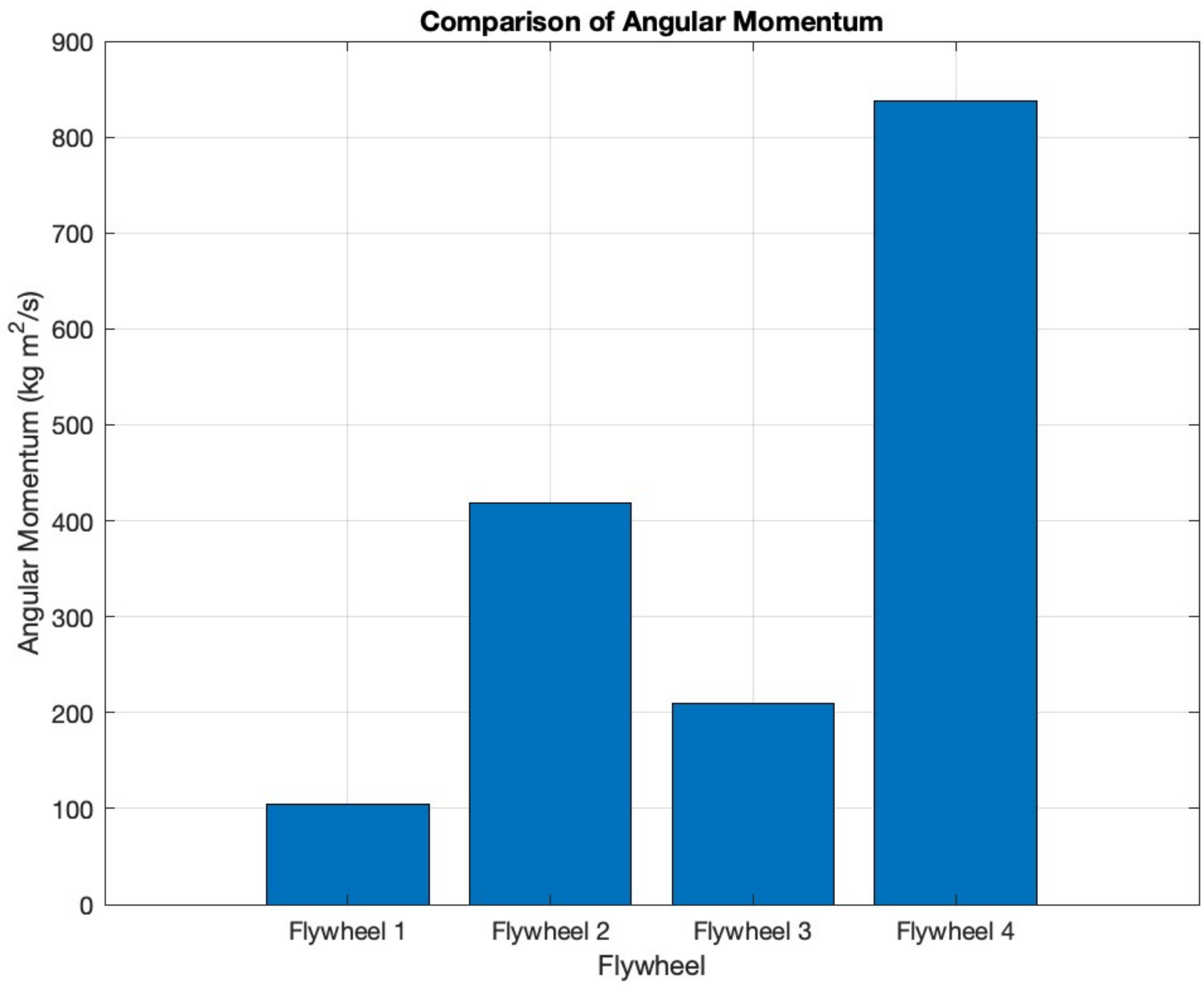


Figure 12: Hoop stress (kN) versus radius (m) of the flywheel

Figure 12 showed that at a constant speed, if the flywheel radius is increased, that the flywheel would experience greater hoop stress. The two flywheels in this graph were both 20 kg. Hoop stress is a type of mechanical stress that arises in objects with rotational symmetry due to forces acting in a circumferential direction, perpendicular to both the object's axis and its radius (Lawlor, 2013). The material properties table (table 5) shows the material properties for steel. The important values from this table related to the flywheels are ultimate tensile strength (UTS), yield strength (YS) and shear modulus (SM). The values of UTS and YS are important values related to hoop stress (Kumar et al., 2017).



.

Figure 13: Angular momentum (kg m2/s) of the four different flywheels

Table 5: Tabulated data of angular momentum for the four different flywheels with variables for mass (Kg) and radius (m)

Flywheel	Mass (kg)	Radius (m)	Angular Momentum (kg.m^2/s)
Flywheel 1	10	0.1	104.72
Flywheel 2	10	0.2	414.88
Flywheel 3	20	0.1	209.44
Flywheel 4	20	0.2	837.76

The graph above (Figure 13) shows angular momentum amongst the four different flywheels. These calculations were added as it shows the tendency of a rotating body to continue rotating, which shows one that a flywheel can store great amounts of energy (Woodford, 2023). This proves that with an increase in mass of the flywheel, that more energy can be stored in the flywheel. These values were calculated at 20000 RPM. Meanwhile, Table 5 has the different values for angular momentum for the four different flywheels. This graph and figure showed that flywheel four produced the greatest angular momentum, based off the largest mass and radius. Meanwhile, flywheel two had the second-largest angular momentum, although with a lower mass compared to flywheel four but an equal sized radius. The two remaining flywheels, one and three, had the same radius but decreased in angular momentum based on decreasing mass.

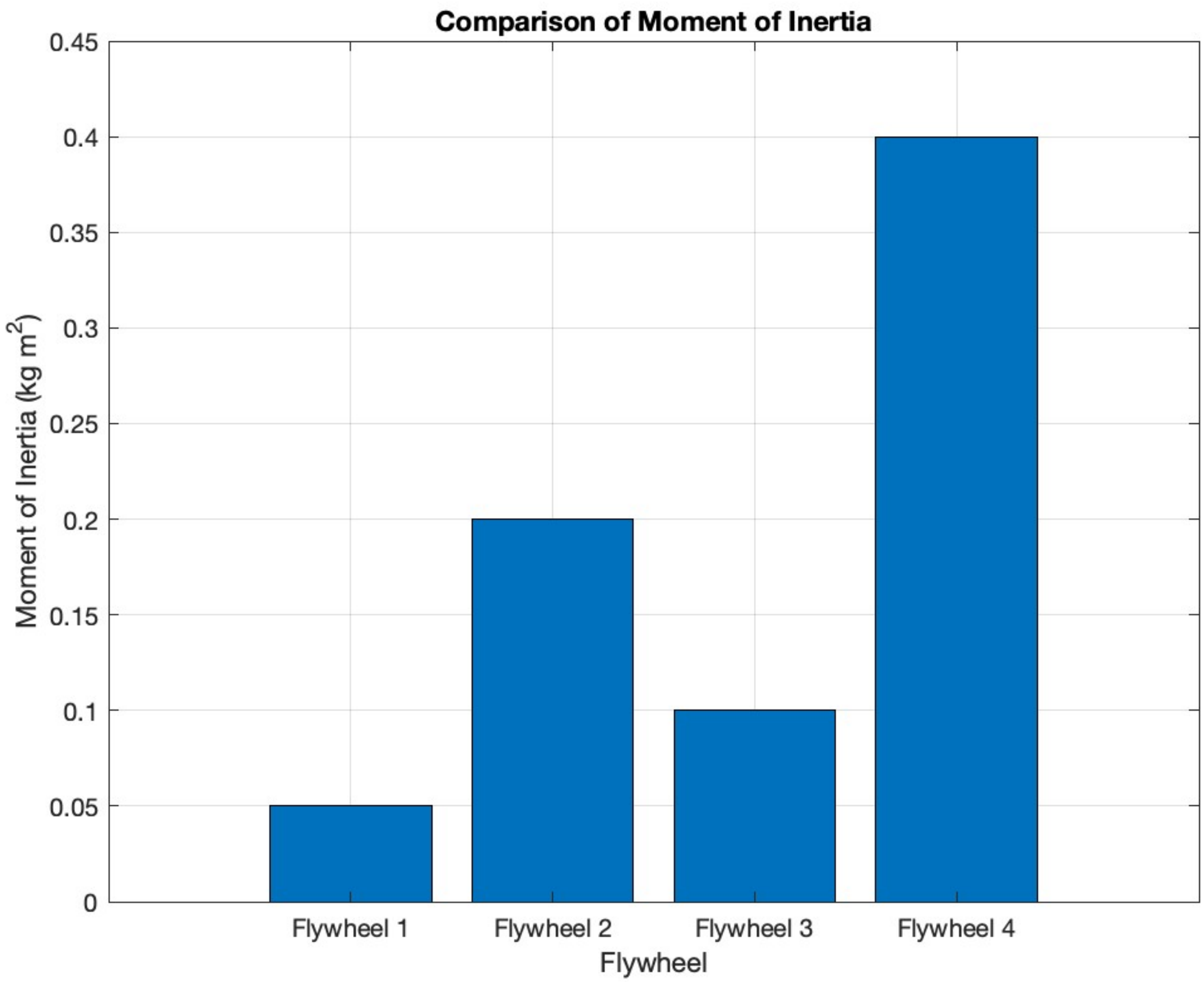


Figure 14: Moment of inertia (Kg m2) for the four different flywheels

Figure 14 shows how mass and radius affect the moment of inertia of the different flywheel configurations. This is shown in the different flywheel configurations. It shows that the greater the mass and radius, the larger the moment of inertia, with mass having a bigger impact on moment of inertia than radius when comparing flywheel two and three. This is as expected because the greater quantity of mass that is placed further away from the centre of rotation results in a greater moment of inertia (Woodford, 2023).

4.1.3 Electric vs Fuel Comparison

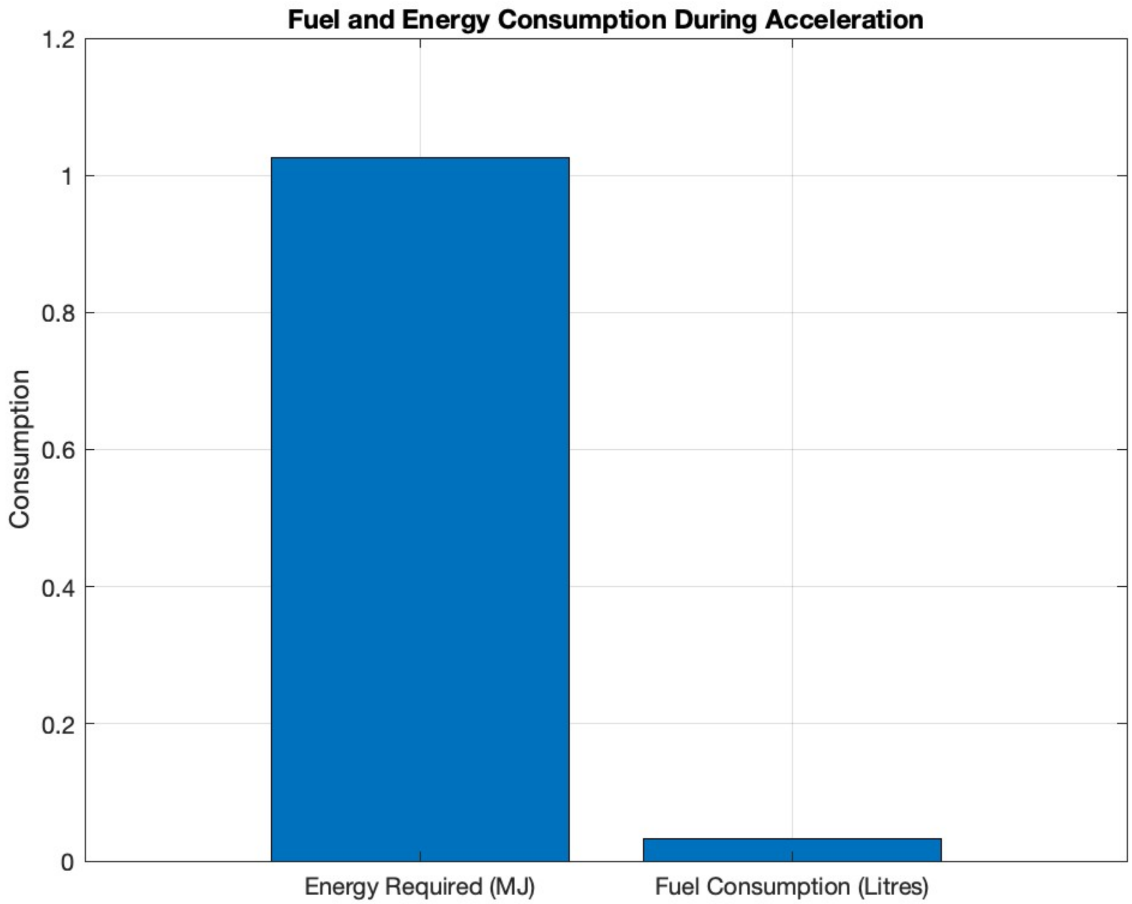


Figure 15: Comparison of energy required (MJ) versus fuel consumption (Litres)

Figure 15 shows that the energy required to accelerate a vehicle to 60km/h in 5 seconds. The vehicle would consume 0.0320 Litres of petrol. This is accelerating the vehicle using only fossil fuels. This value was used to calculate the cost difference of energy sources. The graph above (Figure 16) shows the velocity of the vehicle over time. The areas under this curve would equal the distance the vehicle has travelled in that time, assuming that the velocity is constant.

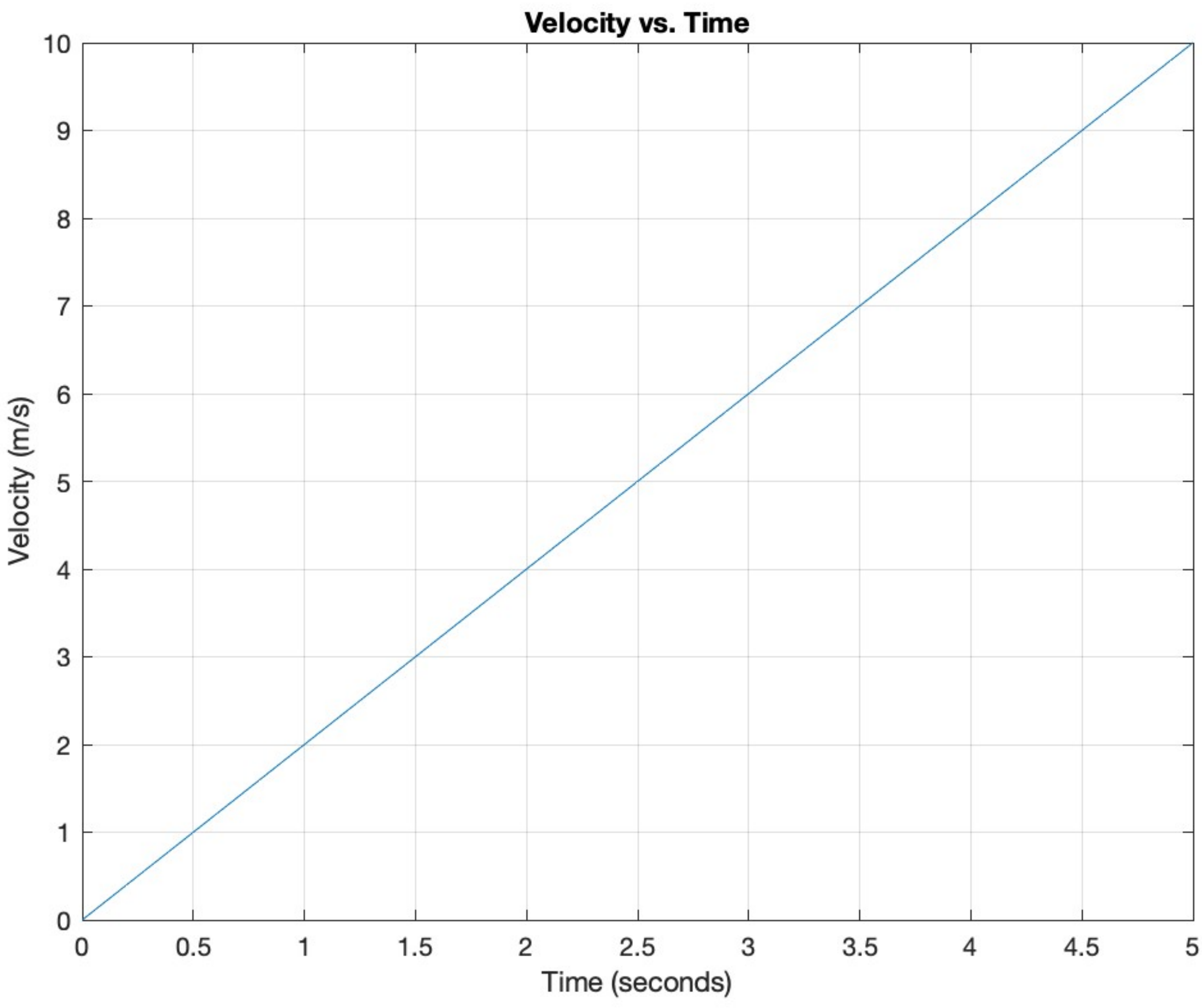


Figure 16: Velocity (m/s) over time (seconds).

4.2 Chemical Battery Calculations (LIB)

4.2.1 LIB Energy Storage

The calculations in this section of the thesis were carried out to be used as a comparison to a FESS. Like the FESS section of the thesis, Matlab has been used to carry out the calculations related to the comparison.

4.3 Comparison Calculations

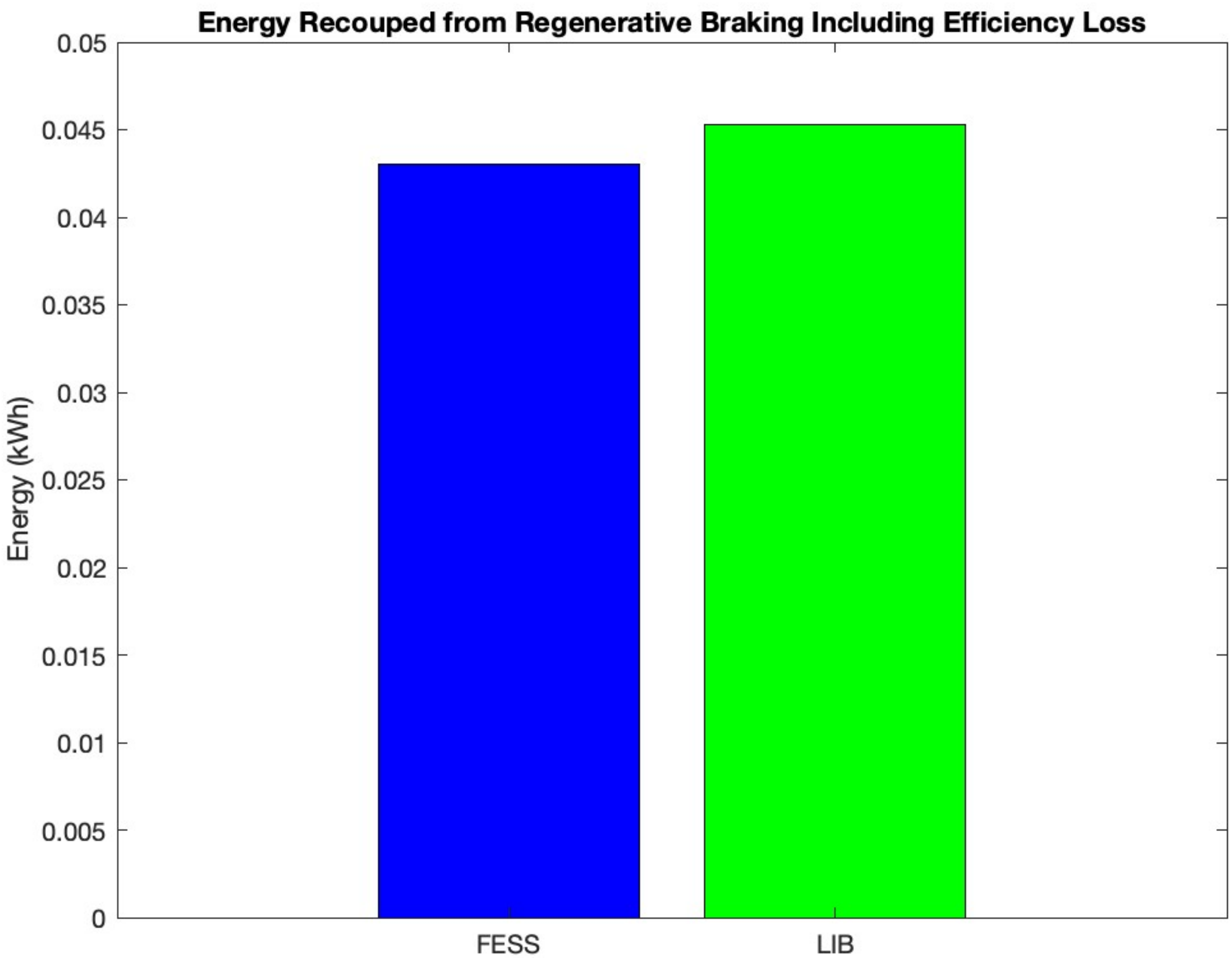


Figure 17: Energy recouped (kWh) in FESS versus LIB

The graph above (Figure 17) compares the energy recouped from regenerative braking in comparison with how much energy the aver EV LIB can store (Eon Energy, 2023). It demonstrates that the LIB recouped a slightly larger amount of energy than the FESS. The values differ due to the greater efficiency pf the LIB system.

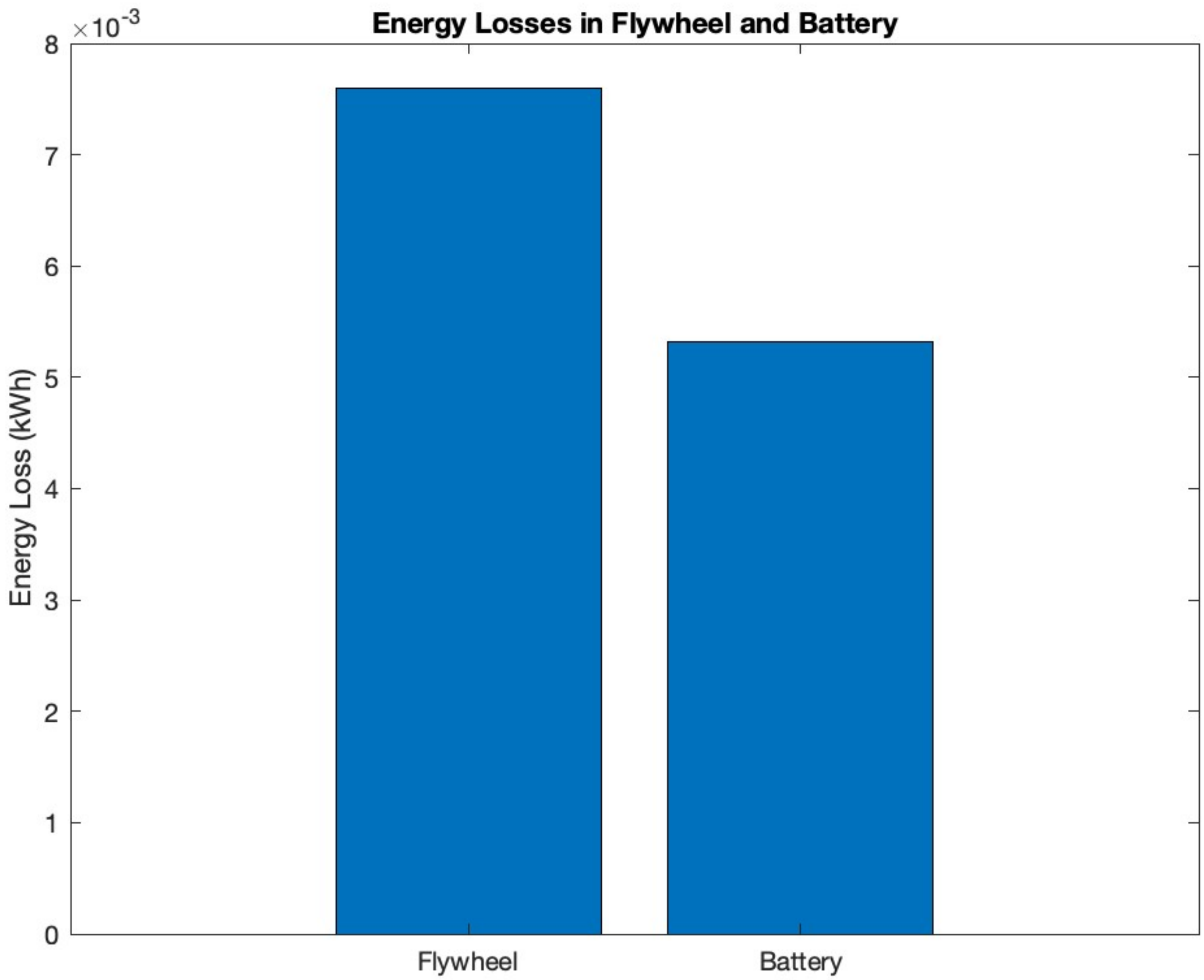


Figure 18: Energy loss (kWh) for flywheel versus chemical battery

The graph above (Figure 18) shows that the flywheel has greater energy losses. This is due to the flywheel continually spinning. This is where the flywheel would be useful for short time delays in start stop scenarios.

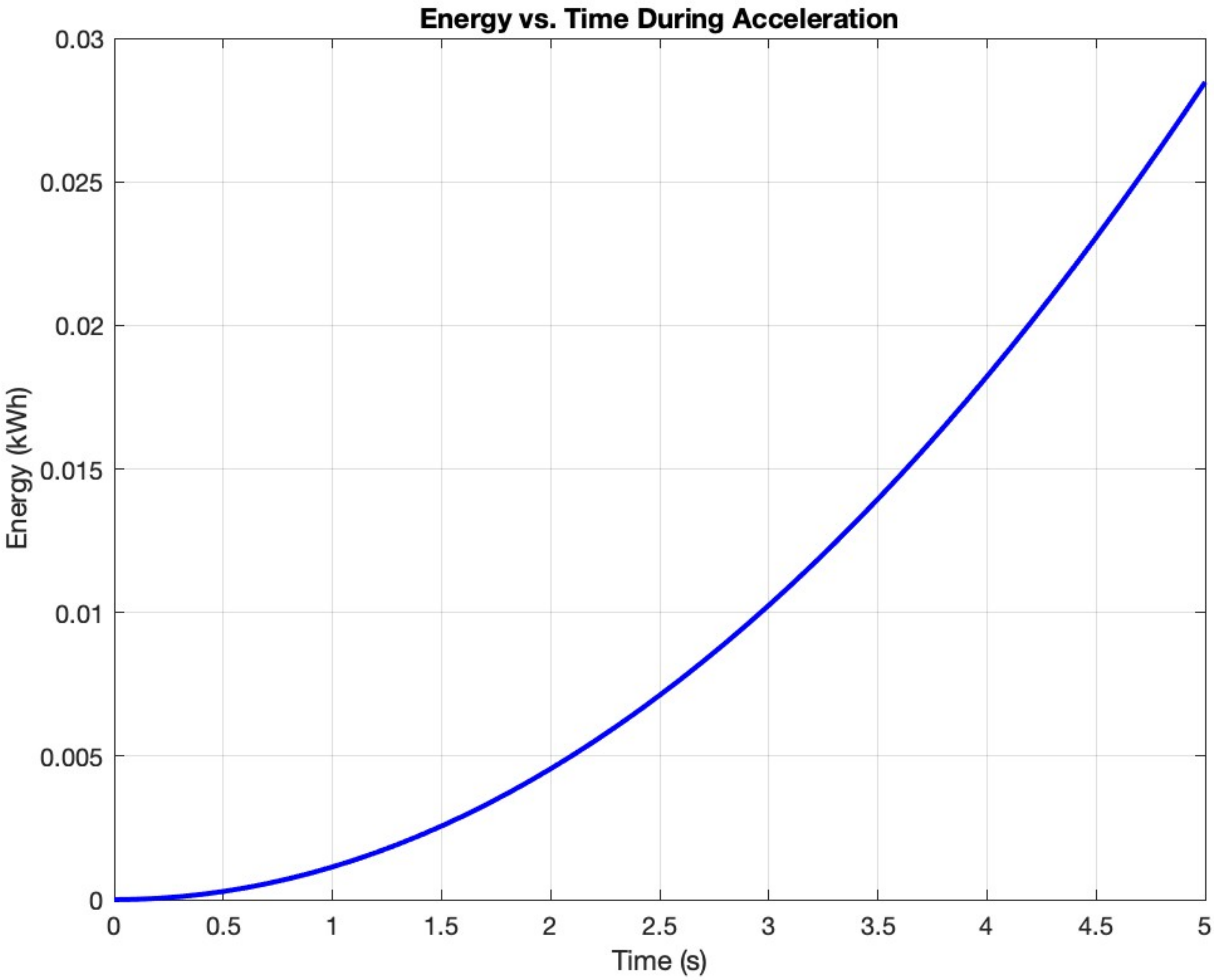


Figure 21: This graphs shows the amount of energy required to accelerate a 2050 kg car from an initial velocity of 0, to 36 km/h over 5 seconds. The recouped energy from the regener-

ative braking amounted to 45 watt-hour (Wh).Converting this to an energy density for the flywheel would be as follows:

$$\text{Energy Density} = \frac{\text{kWh}}{\text{kg}}$$

$$\text{Energy Density} = \frac{45\text{Wh}}{20\text{kg}}$$

$$\text{Energy Density} = 2.25 Wh/kg$$

The equations above were used to calculate the theoretical energy density of flywheel 4. Given the calculated regenerative energy values, the energy density is 2.25 Wh/kg

1. **Convert the initial and final velocities to meters per second (m/s):**
   - Initial velocity: $0\ \text{km/h}$ is equivalent to $0\ \text{m/s}$.
   - Final velocity: $60\ \text{km/h}$ is equivalent to $\frac{60\times1000}{3600}\ \text{m/s}$.
2. **Calculate the change in kinetic energy (Joules):**
   $\Delta KE = \frac{1}{2} \times \text{mass} \times (\text{final velocity}^2 - \text{initial velocity}^2)$
3. **Convert the energy from Joules to kilowatt-hours (kWh):**
   - Use the conversion factor $1\ \text{Joule} = 2.77778 \times 10^{-7}\ \text{kWh}$.

The three equations above were used to calculate how much energy in kWh are required to accelerate the car in this thesis to 60km/h. It was calculated that 0.08 kWh or 80 Wh is required to accelerate the car to 60km/h.

1. **Change in Kinetic Energy during Acceleration (Joules):**
   $\Delta KE = \frac{1}{2} \times \text{mass} \times (\text{final velocity}^2 - \text{initial velocity}^2)$
2. **Energy Recovered during Regenerative Braking (kWh):**
   $\text{Recovered Energy (kWh)} = \Delta KE \times \text{Regeneration Efficiency Factor} \times \text{Joules to kWh Conversion Factor}$
3. **Energy Required for Acceleration (kWh):**
   $\text{Energy Required (kWh)} = \Delta KE \times \text{Joules to kWh Conversion Factor}$
4. **Energy Contribution from the Internal Combustion Engine (kWh):**
   $\text{Engine Energy Needed (kWh)} = \text{Energy Required (kWh)} - \text{Recovered Energy (kWh)}$

The four equations above were used to calculate the amount of energy required by an ICE to accelerate the vehicle to 60 km/h in conjunction with using the energy that had been stored from regenerative braking. With an initial velocity of 60km/h and coming to a stop, it was calculated that the ICE would need to contribute 20 Wh of energy to accelerate the vehicle back to 60km/h.

The results suggest that it is feasible to increase the kilometres driven per litre of fuel in urban driving conditions using in wheel motors and a LIB as the ESS. The efficiency and material problems related to FESS might not be suitable.

5 Discussion

5.1 Lithium-ion battery versus Flywheel Energy Storage System

LIB's and FESS represent two distinct yet highly valuable approaches to energy storage, each with its own set of advantages and limitations. This discussion will explore these two energy storage technologies, investigating their key characteristics and their differences.

A value of 0.0791 kWh of energy is recouped through the regenerative braking process as shown in Figure 5. The difference between the power in kWh required to accelerate an average vehicle of mass 2050 kg, to the average speed of vehicles travelling in a metropolis area (36km/h), was almost three times less at 0.0285 kWh. The proportion of this energy that could be regenerated is around 70% (Boretti, 2013). This would lead to a figure of approximately 0.055 kWh. Due to energy loss, the FESS would only be able to recoup 0.04556 kWh as shown in Figure 3. The energy regenerated would then be used to propel the vehicle. It has been calculated that to accelerate the vehicle to 36km/hr, as per the specified parameters, requires 0.03 kWh of energy. This shows that the flywheel can indeed store regenerated energy and reintroduce that energy into the system. From these figures, it could be deducted that the vehicle could be solely accelerated using the regenerative energy. Furthermore, if the required speed is greater than the average speed of 36km/h, the regenerative energy can be used in conjunction with the ICE to accelerate the vehicle to the desired speed, and potentially minimising the entire reliance on ICE and fossil fuel to reach the intended speed.

A value of 8647 RPM was the calculated rotational speed flywheel 4 would reach if it were to be charged from stand still from the energy recouped above. This value is shown in Figure 8 of the results section. This value was calculated using the amount of energy that was calculated from the regenerative braking efforts. For round trip times of up to 10 seconds, these values are still relevant. Calculations for Figure 8 show that the FESS system will spin for a long time after it has been charged with the energy recouped from the regenerative braking activity. The amount of usable energy would be dependent on the efficiency of the electrical system as well as the amount of time between the flywheel being charged and then the energy being reintroduced to the wheel. The round trip in this context is referred to power generated from regenerative braking, charging up the flywheel (mechanical battery) and then discharging the flywheel battery's power back to the in-wheel motors. The values for the four combinations of flywheels were calculated to be between 0.030 kWh and 0.244 kWh at 20000 rpm (Table 4). Figure 7 further illustrates this data. The values of mass of the flywheel varied from 10kg to 20 kg for these calculations. This means that the FESS is capable of storing the energy however, it with an increase in mass, means more mass within the vehicle to cart. Research has shown that with stationary FESS, they are capable of holding significantly more energy in static configurations (Mathivanan et al., 2023). However, the mass is significantly greater thus the large system would not be suitable.

Meanwhile, the radius of the flywheel varied from 10 centimetres (cm) to 50 cm. Assuming round trip efficiency of 90%, this means that there would be the potential for the regenerative energy to make a considerable difference in overall energy consumption of the vehicle. With this being said, this would come down to the actual efficiency of the electronic control components as well as other factors including vehicle geometry, road conditions etc. Further to this, the value of 0.544 kWh, assuming 90% efficiency, would spin the flywheel in excess of 190000 rpm. Physical experiments would be required to verify these values. This value has also been calculated without taking into account losses such as friction, heat et cetera.

It was calculated that flywheel 4 would spin for 75 minutes, taking into account that the system is 100% efficient. Figure 9 shows the amount of energy in joules as well as how long the flywheel 4 will spin for in seconds. The area would equal the amount of energy stored in kWh. Figure 10 demonstrates that the smaller the mass and radius of the flywheel, showing it will allow for greater RPMs to be reached. Flywheel 1 reached the highest RPM whereas flywheel 4 had the lowest RPM. These figures were to be expected. These calculations were done to aid in the future selection of components, if the project were to move onto the prototyping stage.

Multiple flywheel configurations were used in the calculations to illustrate how mass, radius and rpm can affect multiple outcomes. Specifically, how it can affect gyroscopic action, energy storage, round trip energy generation and use, as well as stress. The parameters used to compare the flywheels were as follows: the flywheel test rpm was set to 20000 rpm, varying vehicle speeds between 30 km/h and 60 km/h. The assumptions listed in the methodology chapter were used in these calculations. Flywheel 1 had the least angular momentum (Figure 13). This was due to it being the smallest of the four flywheels with the lowest value for mass and radius. This leads into the moment of inertia for this flywheel also being the lowest value (Figure 14). With a lower value for inertia, this flywheel would not be put forth as a consideration for future use in such a configuration.

The calculations supported the retrofitting of regenerative braking systems to in-wheel mechanical batteries. This statement is based off on the following findings. It was found that between regenerative braking properties and energy required to accelerate the vehicle to metropolis average speed, did not differ significantly. Essentially, this means that because the average speed in the metropolis area is around 36km/h per hour, the mechanical battery (flywheel) is suitable in meeting the required task put forward. An example of this is shown in the results section. It is stated there that storage capacity of the four different flywheel configurations ranged between 0.031 kWh and 0.244 kWh at 20000 rpm, which shows that flywheels can store sufficient energy required for this proposed application. Specifically, it is able to store the energy required for quick succession slow down stop-start. However, as time increases between charging the flywheel, the available power from the flywheel would decrease in a real world due to factors of friction as shown in figure 8. This could be minimised if the flywheel were housed within a hermetically sealed chamber (Douglas, 2019). The practicality of this would require service intervals to explore how the seals and other components within the flywheel system would degrade over time.

Furthermore, the results found that the flywheel radii and mass could be modified to suit a variance of passenger vehicles. The angular velocity of the flywheel could be seen as solely dependent on the kinetic energy that is regenerated from the BERS of the vehicle. This once again lends this system to a variance of vehicles. The effects of the inertia of the flywheel when mounted transversely would have the same effect as an east-west motor configuration. When mounted transversely, the yaw roll of the vehicle would be effected and stiffer suspension across the transverse section of the drive shafts could minimise this issue. Practical experiments into this section would be required to support this mathematical finding. The results of this project did find this system would be suitable for city driving, however, it could not be relied on when driving on highways and country roads where start / stop /start cycles are more infrequent. This is because the flywheel will not be continually energised from the BERS start / stop/ start cycle.

There are trade-offs between multiple attributes of a flywheel. The first trade-off lies within the material of the flywheel (Rocca et al., 2020). The material has to be able to fulfil energy storage requirements and be able to withstand the stresses and forced associated with a spinning disc (Rocca et al., 2020). These forces increase with an increase in radius, mass and RPM (Ha et al., 2006). The calculations related to figure 11 show that these forces exist and should be taken into account when selecting a material for the flywheel. The centrifugal forces and other characteristics of the flywheel material determine the maximum speed (RPM) the flywheel can spin at before resulting in failure (Olabi et al., 2021). Furthermore, stresses of other components connected to the flywheel would also be subject to these forces (Beno et al., 2001). When designing the final product, these calculations would be taken into account to ensure that these modes of failure do not occur. This issue ties in with the trade-off of radius of the flywheel (CTCN, 2013). The radius of the flywheel can impact the location of where the flywheel system would be housed within the vehicle. Like the radius, the mass also has an impact on where the flywheel would be mounted into the vehicle. A positive trade-off to this would be that the greater the mass and radius of the flywheel, the more energy can be stored as shown in the results section of this thesis (Figure 7). The negative trade-off would be how quickly the energy can be stored and discharged (Xiang et al., 2022).

The occurrence of gyroscopic motion has been explained earlier in this thesis. From the four configurations of flywheels, the angular momentum of each flywheel at 20000rpm was calculated (Table 5). The calculations have shown that with an increase in mass and radius of the flywheel, there is an increase in angular momentum (Figure 13). These values can be used later to determine the placement of the flywheel assembly in the vehicle. The moment of inertia was calculated for all four configurations of the flywheel (Figure 14). All four flywheels were uniform in shape. Figure 4 (?) shows the values of relating to moment of inertia for the four configurations. Once again, the higher values for the moment of inertia are related to an increase in mass and radius as seen in Figure 4.

The stress and forces related to the four flywheel configurations were also calculated. The results found, as shown in Figure 11, that with an increase in mass, there was an increase in centrifugal forces of the flywheel. The values were compared, and it found that radius does not have a great effect on centrifugal forces (Figure 11).Figure 11 shows that with an increase in mass, there is an increase in centrifugal forces. Figure 11 shows that flywheel 1 and flywheel 3 have the same radius, yet the masses differ by 10 kg, which shows a result that a great centrifugal forces are experienced with greater mass. The Calculations related to hoop stress of the flywheel configurations resulted in showing that with an increase in radius, the hoop stress increases (Figure 12). As an example, steel was used to as a comparison to the values of hoop stress and how it might affect the operation of the flywheel at certain rpm. These results show that the hoop stress is 450 Megapascals. Comparing this value to the values shown in table 5 in the appendix section, this particular grade of steel shouldn't be used as the value for the yield strength (350MPa) and ultimate tensile strength (420 MPa) is less than that of the calculated hoop stress (figure 12, 450 MPa). If this grade of steel were to be used, failure would most likely occur.

When comparing the FESS and LIB system, the results showed that the LIB system was more efficient than the FESS (Figure 17). This is due to the efficiency losses in a FESS system such as friction as well as no way to stop the system releasing energy due to the conservation of energy and conservation of momentum. In a real world setting, bearings are one of the main causes of energy loss (Martin et al., 2016). This leads on to Figure 18 which shows the potential for great energy loss in the regenerative braking process due to the FESS inefficiencies listed above. This energy loss due to the bearings could be mitigated through the use of magnetic bearings (Martin et al., 2016), however, this would only be suitable for a stationary FESS (Kasarda et al., 2000).

There are many parameters that need to be met in order for the FESS to be a useful ESS in an automotive application. From the research conducted for this thesis, the LIB lends itself to holding energy for longer periods of time without wasting the majority of energy. This thesis showed through the research and calculations, that although the FESS can hold the regenerative energy, the LIB still remains the optimum choice for ESS within the automotive industry. The required amount of energy to accelerate the vehicle mentioned in this thesis, to the average metropolis speeds, is relatively low in terms of what a LIB can store. The average EV battery has the energy density of 271 Wh/kg as mentioned in the Energy Storage Systmes section of this thesis. The calculations show that the amount of energy that can be recouped from regenerative braking of 0.0445kWh (figure 17) would be enough to accelerate the vehicle to the average speeds seen in metropolis areas (36km/h). The result of the calculation (figure 21) shows that 28 Wh is required to accelerate the vehicle to 36km/h. The recouped amount of energy from the regenerative braking amounted to 45Wh. The average EV battery has a storage capacity of 69.2 kWh. From the battery density mentioned above, this would then equate to a battery that would weigh about 233 kg for a solely electric vehicle. If one were to put a 2 kWh LIB into the car mentioned, it would only have a mass of around 7.5 kg. This shows that the LIB would be a better option to store the recouped energy than that of the FESS due to the mass of the battery being nearly two thirds to three times less than the configuration of the 4 flywheels. Further to this, the energy density of flywheel 4 was calculated. Flywheel 4 was chosen as the comparison as it could technically store the most energy. Using the value of regenerative energy of 45Wh, it was calculated that flywheel 4 has an energy density of 2.25Wh/kg. With flywheel 4's mass being nearly three times greater than the 2 kWh LIB, it would be recommended from an energy density point of view to rather use the LIB as the ESS for this system instead of the FESS. Overall, a recommendation based on the research is that the FESS system would not be feasible in relation to the comparison to the LIB.

This thesis provided the mathematical basis to show that it is theoretically possible to increase the kilometres driven per litre of fuel in urban areas and retrofitting electric hub motors and LIB ESS, is indeed theoretically possible. The analysis of retrofitting electric motors and mechanical batteries is still lacking solid evidence that it is a viable solution and is worth exploring further. This research could be conducted as previously outlined. In conclusion, retrofitting electric hub motors and mechanical batteries to ICEV is indeed possible and presents a promising avenue for the automotive industry.. In the comparison calculations section, it was calculated that it would require 0.08kWh of energy to accelerate the vehicle to 60km/h. The energy recouped was then calculated and was shown to 0.06 kWh. this mean that if the efficiencies of the systems in discussion were at 100%, that this system would indeed increase the kilometres driven per litre of fuel in urban areas.

5.2 Limitations & Future Research

The major limitations of this project are considered to be the availability of materials and access to subject-matter experts (SME's) within the industry. Furthermore, the aim of the project, as per the title, is to retrofit hub motors to the un-driven wheels of a fossil fuelled vehicle. This is easily said, but the thought process and requirements to manage the system is extremely complex. Knowledge of suitable materials, control systems and motor / generators, along with how they may behave in changing environments and circumstances is another limitation at this point. Further research in this area would add to the body of knowledge and further explore the existing gap in the field.

Due to the limitation of time, the initial hope of building a small scale prototype was found to be beyond the scope of this project. The R/C car would have lent itself to this idea due to their readiness to be modified. The idea was that an electric motor shall be attached to the un-driven wheels of the R/C car. The electric motor shall act as both a motor and a generator. When the brakes of the R/C car are applied, the electric motor will operate as a generator, in the hopes to see a return in energy generated. There is the possibility of further research to continue this avenue of research. Limitations related to the flywheel in this thesis include the issue of energy storage time. Once the flywheel has been charged, there is no way to stop the flywheel dissipating kinetic energy. If the flywheel is spinning, it is dissipating energy. This is a limitation of this system that needs to be further investigated.

6 Conclusions

The aim of this project was to determine if it was feasible to increase the kilometres driven per litre of fuel in urban areas through retrofitting electric motors to the un-driven wheels of a fossil fuelled vehicle Furthermore, comparing a FESS versus LIB as the most suitable ESS for to answer the question, and in the process answer the research questions as outlined in the objectives section. The research question being "is it theoretically possible to increase the kilometres driven per litre of fuel in urban areas? In conjunction to this, is it feasible to retrofit electric motors to un-driven wheels of a fossil fuelled vehicle using either a FES or a LIB as an energy storage system?". This question was answered through undertaking the objectives of this thesis, via the method of mathematical modelling and research related to the properties of LIB's. This thesis provided the mathematical basis to show that it is theoretically possible to increase the kilometres driven per litre of fuel in urban areas and retrofitting electric hub motors and LIB ESS, is indeed theoretically possible. However, the results found that the mechanical battery isn't as efficient as LIB. Furthermore, the price of materials for lithium batteries is estimated to decrease by up to 30% by 2025 (Amry et al., 2023).The cost of the retrofit process will hopefully be cheaper and more affordable for the majority. The analysis of retrofitting electric motors and mechanical batteries is still lacking solid evidence that it is a viable solution and is worth exploring further. This research could be conducted as previously outlined. In conclusion, retrofitting electric hub motors and mechanical batteries to ICEV is indeed possible and presents a promising avenue for the automotive industry.

7 References

References

Ahn, J.K.,, Jung, K.H.,, Kim, D.H.,, Jin, H.B.,, Kim, H.S., & Hwang, S.H., 2009. Analysis of a regenerative braking system for hybrid electric vehicles using an electro-mechanical brake. International Journal of Automotive Technology, 10(2), pp.229–234.

Alami, A. H. (2012). Investigation in utilizing buoyancy forces for mechanical energy storage. International Journal of Advances and Trends in Engineering Materials and Their Applications, 1, 51-60.

Alcoberro, R.,, Durakbasa, N.,, Bauer, J., & Kopacek, P., 2021. A low-cost integrated concept for the hybridisation and electric conversion of cars and other mechatronic vehicles. IFAC-PapersOnLine, 54(13), pp.511–516.

Amrr, S. M., Alturki, A., &; Zafar, K. (2022). Advanced robust control design for the support of fast rotating shaft using active magnetic bearings. Transportation Engineering, 10, 100139. https://doi.org/10.1016/j.treng.2022.100139

Annamalai, M.C., and Amutha Prabha, N., 2023. A comprehensive review on isolated and non-isolated converter configuration and fast charging technology: For battery and plug in Hybrid Electric Vehicle. Heliyon, 9(8).

Anon, 2022. In-Wheel Gallery. [online] Elaphe. Available at: https://in-wheel.com/en/gallery/; [Accessed 4 Sep. 2023].

Anon, 2020. What is the difference between a brushless and a brushed motor? [online] What's the Difference Between a Brushless and a Brushed Motor? Available at: https://www.powerelectric.com/motor-resources/motors101/what-is-the-difference-between-a-brushless-and-a-brushed-motor; [Accessed 5 Sep. 2023].

Anon, n.d. Discounted registration for zero and low emission vehicles. [online] Access Canberra. Available at: ;https://www.accesscanberra.act.gov.au/s/article/motor-vehicle-registration-and-renewal-tab-zero-emissions-vehicle-registration; [Accessed 4 Sep. 2023].

Anon, n.d. FOTW #1234, April 18, 2022: Volumetric energy density of lithium-ion batteries increased by more than eight times between 2008 and 2020. [online] Energy.gov. Available at:https://www.energy.gov/eere/vehicles/articles/fotw-1234-april-18-2022-volumetric-energy-density-lithium-ion-batteries; [Accessed 4 Sep. 2023].

Anon, n.d. [online] Electricity generation. Available at: https://www.energy.gov.au/data/electricity-generation; [Accessed 4 Sep. 2023].

Babar, A. H., Ali, Y., &; Khan, A. U. (2020). Moving toward green mobility: Overview and analysis of Electric Vehicle Selection, Pakistan a case in point. Environment, Development and Sustainability, 23(7), 10994–11011. https://doi.org/10.1007/s10668-020-01101-5

Beno, J. H., Thompson, R. C., Werst, M. D., Manifold, S. M., &; Zierer, J. J. (2001). End-of-life design for composite rotors [flywheel systems]. IEEE Transactions on Magnetics, 37(1), 284–289. https://doi.org/10.1109/20.911838

Bhutada, G., 2022. Visualizing the range of electric cars vs. gas-powered cars. [online] Visual Capitalist. Available at: https://www.visualcapitalist.com/visualizing-the-range-of-electric-cars-vs-gas-powered-cars; [Accessed 4 Sep. 2023].

Boldea, I. (2017). Electric generators and motors: An overview. CES Transactions on Electrical Machines and Systems, 1(1), 3-14. https://doi.org/10.23919/TEMS.2017.7911104.

Borah, R.,, Hughson, F.R.,, Johnston, J., & Nann, T., 2020. On battery materials and methods. Materials Today Advances, 6, p.100046.

Boretti, A. (2013). Analysis of the regenerative braking efficiency of a latest electric vehicle. SAE Technical Paper Series. https://doi.org/10.4271/2013-01-2872

Brakels, R., 2022. To electrify road transport Australia will need 46% more generation. [online] Solar Quotes Blog. Available at: ;https://www.solarquotes.com.au/blog/electrify-road-transport-australia; [Accessed 4 Sep. 2023].

Bravo, R. R., De Negri, V. J., &; Oliveira, A. A. (2018). Design and analysis of a parallel hydraulic – pneumatic regenerative braking system for heavy-duty hybrid vehicles. Applied Energy, 225, 60–77. https://doi.org/10.1016/j.apenergy.2018.04.102

Bruchhausen, M.,, Hildebrand, S.,, Kriston, A.,, Ruiz, V.,, Podias, A., and Pfrang, A., 2023. Evaluation of detection criteria for thermal runaway experiments on commercial cells for electric vehicles. Energy Reports, 10, pp.510–519.

Chen, W.,, Liang, J.,, Yang, Z., and Li, G., 2019. A review of lithium-ion battery for electric vehicle applications and beyond. Energy Procedia, 158, pp.4363–4368.

Chen, Q.,, Lai, X.,, Chen, J.,, Yao, Y.,, Guo, Y.,, Zhai, M.,, Han, X.,, Lu, L., and Zheng, Y., 2023. Comparative environmental impacts of different hydrometallurgical recycling and remanufacturing technologies of lithium-ion batteries considering multi-recycling-approach and temporal-geographical scenarios in China. Separation and Purification Technology, 324, p.124642.

Chombo, P. V., & Laoonual, Y. (2020). A review of safety strategies of a Li-Ion Battery. Journal of Power Sources, 478, 228649. https://doi.org/10.1016/j.jpowsour.2020.228649

Chuang, H.-C., Li, G.-D., &; Lee, C.-T. (2019). The efficiency improvement of AC induction motor with Constant Frequency Technology. Energy, 174, 805–813. https://doi.org/10.1016/j.energy.2019.03.019

Cui, Y.,, Liu, J.,, Han, X.,, Sun, S., and Cong, B., 2022. Full-scale experimental study on suppressing lithium-ion battery pack fires from Electric Vehicles. Fire Safety Journal, 129, p.103562.

Craft, M., 2023. [online] What's the average weight of a car? Available at: ;https://www.carsguide.com.au/car-advice/whats-the-average-weight-of-a-car-89728; [Accessed 4 Sep. 2023].

Dakkoune, A., Vernières-Hassimi, L., Leveneur, S., Lefebvre, D., &; Estel, L. (2019).

Analysis of thermal runaway events in French Chemical Industry. Journal of Loss Prevention in the Process Industries, 62, 103938. https://doi.org/10.1016/j.jlp.2019.103938

Dragon Fly, 2022. Why does energy density matter in batteries? [online] Dragonfly Energy. Available at: ;https://dragonflyenergy.com/why-does-energy-density-matter-in-batteries/; [Accessed 4 Sep. 2023].

Deng, Y., Chen, Z., Yan, P., & Zhong, R. (2023). Battery swapping and management system design for electric trucks considering battery degradation. Transportation Research Part D: Transport and Environment, 122, 103860. https://doi.org/10.1016/j.trd.2023.103860

Douglas, E. (2019) Hermetic feedthroughs critical for flywheel energy storage, Tech Briefs. Available at:https://www.techbriefs.com/component/content/article/tb/supplements/mct/features/articles (Accessed: 08 October 2023).

EV Database, 2023. Useable battery capacity of full electric vehicles. [online] EV Database. Available at https://ev-database.org/cheatsheet/useable-battery-capacity-electric-cargt; [Accessed 15 Oct. 2023].

Evers, A. (2023, July 7). Converting gas-powered cars to EVS is a booming business. Converting gas-powered cars to EVs is a booming business. https://www.cnbc.com/2023/06/16/converting-gas-powered-cars-to-evs-is-a-booming-business.html

Elaphe. (2023, September 12). Elaphe home. Elaphe. https://in-wheel.com/en/

Eon, 2023. Electric vehicles: Battery: Capacity and lifespan. [online] Electric vehicles — Battery — Capacity and Lifespan. Available at: <https://www.eonenergy.com/electric-vehicle-charging/running-costs-and-benefits/battery-capacity-and-lifespan.html> [Accessed 12 Oct. 2023].

EXRO. (2022). Barriers to electric vehicle adoption: The 4 key challenges. EXRO. https://www.exro.com/industry-insights/barriers-to-electric-vehicle-adoption-in-2022

Finnerty, J., 2023. Average electric car range in 2023 is 219 miles - enough to drive two weeks on a single charge. [online] GRIDSERVE. Available at: ;https://www.gridserve.com/2023/01/05/average-electric-car-range-in-2023-is-219-miles-enough-to-drive-two-weeks-on-a-single-charge/; [Accessed 4 Sep. 2023].

Folkson, R., & Sapsford, S. (2022). Alternative fuels and advanced vehicle technologies for improved environmental performance: Towards zero carbon transportation. Woodhead Publishing.

Gao, Y.,, Chen, L., and Ehsani, M., 1999. Investigation of the effectiveness of regenerative braking for EV and Hev. SAE Technical Paper Series.

García-Afonso, Ó., and González-Díaz, B., 2023. Effectiveness of zero tailpipe vehicles to reduce CO2 emissions in Isolated Power Systems, a realistic perspective: Tenerife island test case. Energy, 273, p.127211.

Guillard, V. (2018). Anticonsumption consciousness in pursuit of sustainability. Journal of Public Policy & Marketing, 37(2), 274–290. https://doi.org/10.1177/0743915618813118

Hamada, A. T., & Orhan, M. F. (2022). An overview of regenerative braking systems. Journal of Energy Storage, 52, 105033. https://doi.org/10.1016/j.est.2022.105033

Hamidah, I.,, Ramadhan, D.F.,, Ramdhani, R.,, Mulyanti, B.,, Pawinanto, R.E.,, Hasanah, L.,, Nandiyanto, A.B.,, Yunas, J., and Rusydi, A., 2023. Overcoming voltage fluctuation in electric vehicles by considering AL electrolytic capacitor-based voltage stabilizer. Energy Reports, 10, pp.558–564.

Hartley, J.A.A.,, McLellan, R.G.,, Richmond, J.,, Day, A.J., and Campean, I.F., 2011. Regenerative braking system evaluation on a full electric vehicle. Innovations in Fuel Economy and Sustainable Road Transport, pp.73–86.

He, X.,, Jiang, J., and Hu, W., 2023. Cross effects of government subsidies and corporate social responsibility on carbon emissions reductions in an Omnichannel Supply Chain

System. Computers amp;amp; Industrial Engineering, 175, p.108872.

Hebner, R.,, Beno, J., and Walls, A., 2002. Flywheel batteries come around again. IEEE Spectrum, 39(4), pp.46–51.

Hedlund, M., Lundin, J., de Santiago, J., Abrahamsson, J., and; Bernhoff, H. (2015). Flywheel Energy Storage for automotive applications. Energies, 8(10), 10636–10663. https://doi.org/10.3390/en81010636

Henze, V. (2022, December 6). Lithium-ion battery pack prices rise for first time to an average of $151/kwh. BloombergNEF. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/

Herrington, R., 2021. Mining our green future. [online] Nature News. Available at: ;https://www.nature.com/articles/s41578-021-00325-9; [Accessed 4 Sep. 2023].

How does regenerative braking work in an electric vehicle? — evup ... (2021) How does regenerative braking work in an electric vehicle? Available at: https://www.evup.com.au/about-evup/ev-news/how-does-regenerative-braking-work (Accessed: 08 October 2023).

Hu, G.,, Huang, P.,, Bai, Z.,, Wang, Q., and Qi, K., 2021. Comprehensively analysis the failure evolution and Safety Evaluation of Automotive Lithium-ion Battery. eTransportation, 10, p.100140.

Hughes, C., 2023. Australia: Number of automobiles by type 2022. [online] Statista. Available at: ;https://www.statista.com/statistics/683552/australia-number-of-vehicles-by-type/#statisticContainer [Accessed 4 Sep. 2023].

Iea, 2023. Executive summary – global EV outlook 2023 – analysis. [online] IEA. Available at: ;https://www.iea.org/reports/global-ev-outlook-2023/executive-summary; [Accessed 4 Sep. 2023].

Iskakov, Z., Bissembayev, K., & Jamalov, N. (2022). Resonance vibrations of a gyroscopic rotor with linear and nonlinear damping and nonlinear stiffness of the elastic support in interaction with a non-ideal energy source. Mechanical Systems and Signal Processing, 170, 108773. https://doi.org/10.1016/j.ymssp.2021.108773

Jain, I.,, Pawaiya, A.S.,, Juneja, K., and Singh, D.K., 2023. Air pollution and its effects on lung health in never-smoker youth of Delhi NCR versus Pauri Garhwal: A comparative cross-sectional study. Medical Journal Armed Forces India.

Ji, W.,, Li, H.,, Li, W.,, He, Z., and Zhao, J., 2023. Novelty method based on thermal trigger mechanism for high energy density lithium-ion battery safety. Journal of Energy Storage, 64, p.107231.

Kafader, U., 2019. DC motors as generators. [online] DC motors as Generators. Available at:https://drive.tech/en/stream-content/dc-motors-as-generators; [Accessed 5 Sep. 2023].

Kaleg, S.,, Hapid, A., and Kurnia, M.R., 2015. Electric vehicle conversion based on distance, speed and cost requirements. Energy Procedia, 68, pp.446–454.

Kasarda, M.E.,, Clements, J.,, Wicks, A.L.,, Hall, C.D., and Kirk, R.G., 2000. Effect of sinusoidal base motion on a magnetic bearing. Proceedings of the 2000. IEEE International Conference on Control Applications. Conference Proceedings (Cat. No.00CH37162).

Kedia, S., 2021. Running brushed DC motors as generators — machine design. [online] Running Brushed DC Motors as Generators. Available at: ;https://www.machinedesign.com/motors-drives/article/21168640/portescap-running-brushed-dc-motors-as-generators; [Accessed 5 Sep. 2023].

Keys, J., and Ayers, R., 2012. The effects of improved vehicle technology on the design of acceleration and deceleration lanes at Freeway entry and exit ramps. [online] University of Southern Queensland Repository. Available at: <https://research.usq.edu.au/item/q1w3y/the-effects-of-improved-vehicle-technology-on-the-design-of-acceleration-and-deceleration-lanes-at-freeway-entry-and-exit-ramps> [Accessed 13 Oct. 2023]

Khaleghian, S.,, Emami, A., and Taheri, S., 2017. A technical survey on tire-road friction estimation. Friction, 5(2), pp.123–146.

Kuchta, D. M. (2022, December 12). Best EV conversion companies of 2023. Treehugger. https://www.treehugger.com/electric-vehicle-ev-conversion-companies-85249

Kumar, R.U.,, Reddy, P.R., and Sitaramaraju, A.V., 2017. Determination of hoop stresses in hydroforming process. Materials Today: Proceedings, 4(8), pp.9133–9140.

Lee, C.-Y., Zhao, H., &; Ma, T. (2011). Pneumatic regenerative engine braking technology for buses and Commercial Vehicles. SAE International Journal of Engines, 4(3), 2687–2698. https://doi.org/10.4271/2011-01-2176

Li, H. X., Edwards, D. J., Hosseini, M. R., &; Costin, G. P. (2020). A review on Renewable Energy Transition in Australia: An updated depiction. Journal of Cleaner Production, 242, 118475. https://doi.org/10.1016/j.jclepro.2019.118475

Li, X., &; Palazzolo, A. (2022). A review of Flywheel Energy Storage Systems: State of the art and opportunities. Journal of Energy Storage, 46, 103576. https://doi.org/10.1016/j.est.2021.103576

Li, Y.,, Liu, Y.,, Chen, Y.,, Huang, S., & Ju, Y., 2022. Projection of end-of-life vehicle population and recyclable metal resources: Provincial-level gaps in China. Sustainable Production and Consumption, 31, pp.818–827.

Luz, S. (2022) The evidence is clear: The time for action is now. we can halve emissions by 2030., Newsroom Post The evidence is clear: the time for action is now. We can halve emissions by 2030. Available at: https://www.ipcc.ch/2022/04/04/ipcc-ar6-wgiii-pressrelease/ (Accessed: 08 October 2023).

Mahmoud, M.,, Ramadan, M.,, Olabi, A.-G.,, Pullen, K., & Naher, S., 2020. A review of mechanical energy storage systems combined with wind and solar applications. Energy Conversion and Management, 210, p.112670.

Mariani, V.,, Rizzo, G.,, Tiano, F.A., & Glielmo, L., 2022. A model predictive control scheme for regenerative braking in vehicles with hybridized architectures via aftermarket kits. Control Engineering Practice, 123, p.105142.

Martin, J.E.,, Rohwer, L.E.S., and Stupak, J., 2016. Elastic magnetic composites for energy storage flywheels. Composites Part B: Engineering, 97, pp.141–149.

Matei, C., 2020. Electric vehicles are poised for their 'Model t' moment. [online] Visual Capitalist. Available at: ;https://www.visualcapitalist.com/electric-vehicles-poised-model-t/; [Accessed 5 Sep. 2023].

Mcgrath, M., 2019. Average kilometres driven in Australia. [online] Budget Direct. Available at: https://www.budgetdirect.com.au/car-insurance/research/average-kilometers-driven.html [Accessed 4 Sep. 2023].

McGuire, B., 2023. Hybrid pioneer: The 1916 Woods Dual Power. [online] Mac's Motor City Garage. Available at: https://macsmotorcitygarage.com/hybrid-pioneer-the-1916-woods-dual-power/ [Accessed 4 Sep. 2023].

MER UK. (2023, March 15). Ev vs ice: Are electric cars worth it?. Mer UK. https://uk.mer.eco/news/ev-vs-ice-are-electric-cars-worth-it

Milivojevic, N.,, Krishnamurthy, M.,, Gurkaynak, Y.,, Sathyan, A.,, Lee, Y.-J., and Emadi, A., 2012. Stability Analysis of FPGA-based control of brushless DC motors and generators using digital PWM technique. IEEE Transactions on Industrial Electronics, 59(1), pp.343–351.

Miller, C., 2014. The Ethics of Energy Transitions. 2014 IEEE International Symposium on Ethics in Science, Technology and Engineering.

Minos, S., 2023. How lithium-ion batteries work. [online] Energy.gov. Available at: https://www.energy.gov/energysaver/articles/how-lithium-ion-batteries-work> [Accessed 11 Oct. 2023].

Mousavi G, S.M.,, Faraji, F.,, Majazi, A., and Al-Haddad, K., 2017. A comprehensive review of Flywheel Energy Storage System Technology. Renewable and Sustainable Energy Reviews, 67, pp.477–490.

Nave, R. (2009). Gyroscope. http://hyperphysics.phy-astr.gsu.edu/hbase/gyr.html

Nnorom, I.C., and Osibanjo, O., 2008. Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. Resources, Conservation and Recycling, 52(6), pp.843–858.

Olabi, A. G., Wilberforce, T., Abdelkareem, M. A., & Ramadan, M. (2021). Critical review of Flywheel Energy Storage System. Energies, 14(8), 2159. https://doi.org/10.3390/en14082159

Purwadi, A., Dozeno, J., & Heryana, N. (2013). Testing performance of 10 kW BLDC motor and LiFePO4 battery on ITB-1 Electric Car prototype. Procedia Technology, 11, 1074–1082. https://doi.org/10.1016/j.protcy.2013.12.296

Qian, L., and Yin, J., 2017. Linking Chinese cultural values and the adoption of electric vehicles: The mediating role of Ethical Evaluation. Transportation Research Part D: Transport and Environment, 56, pp.175–188.

Rashid, M.I., and Danial, H., 2017. Advisor simulation and performance test of split plug-in Hybrid Electric Vehicle Conversion. Energy Procedia, 105, pp.1408–1413.

Reato, F. M., Ricci, C., Misfatto, J., Calzaferri, M., & Cinquemani, S. (2023). Multi-physics model of DC Micro Motors for Dynamic Operations. Sensors and Actuators A: Physical, 361, 114570. https://doi.org/10.1016/j.sna.2023.114570

Rocca, R. et al. (2020) 'Design trade-offs and feasibility assessment of a novel one-body, laminated-rotor flywheel switched reluctance machine', Energies, 13(22), p. 5857. doi:10.3390/en13225857.

Salehi, M., Noordermeer, J. W. M., Reuvekamp, L. A. E. M., & Blume, A.

(2020). Parameter optimization for a laboratory friction tester to predict tire ABS braking distance using design of experiments. Materials & Design, 194, 108879. https://doi.org/10.1016/j.matdes.2020.108879

Scott, C., 2020. Some of the challenges to your modern EV conversion - canbus. [online] Harden Electric. Available at: https://www.hardenelectric.com.au/canbus-issues/ [Accessed 5 Sep. 2023]. [Accessed 11 Oct. 2022].

Sovacool, B.K.,, Hook, A.,, Martiskainen, M.,, Brock, A., and Turnheim, B., 2020. The decarbonisation divide: Contextualizing landscapes of low-carbon exploitation and toxicity in Africa. Global Environmental Change, 60, p.102028.

Steelplates. (2023, March 4). Stainless steel sheets in Australia, SS plates in Australia. Steel Plates Suppliers — Stainless Steel Sheets/Plates Suppliers, Manufacturers. https://steelplates.in/suppliers/australia/stainless-steel-sheets-plates-in-australia/

Tang, J. (2019, June 21). Eliminate motor speed fluctuations caused by input voltage or load variance. Eliminate Motor Speed Fluctuations Caused By Input Voltage or Load Variance. https://blog.orientalmotor.com/eliminate-motor-speed-fluctuations-due-to-input-voltage-or-load-variance

Taylor, M.A.P., , E.S., 2003. Travelling smarter down under: Policies for voluntary travel behaviour change in Australia. Transport Policy, 10(3), pp.165–177.

Toh Xiang Wen, M., &; Tong Kum Tien, D. (2018). Analysis of a hybrid mechanical regenerative braking system. MATEC Web of Conferences, 152, 02011. https://doi.org/10.1051/matecconf/201815202011

Trajkovic, S., Tunestål, P., &; Johansson, B. (2013). A study on compression braking as a means for brake energy recovery for pneumatic hybrid powertrains. International Journal of Powertrains, 2(1), 26. https://doi.org/10.1504/ijpt.2013.052657

Villatico, F., Zuccari, F., 2008. Efficiency comparison between FC and ice in real urban driving cycles. International Journal of Hydrogen Energy, 33(12), pp.3235–3242.

University of Calgary. (2014, June). Gyroscopic motion. Gyroscopic motion - Energy Education. https://energyeducation.ca/encyclopedia/Gyroscopic_motion

Walzberg, J.,, Sethuraman, S.,, Ghosh, T.,, Uekert, T., Carpenter, A., 2023. Think before you throw! an analysis of behavioral interventions targeting PET bottle recycling in the United States. Energy Research amp;amp; Social Science, 100, p.103116.

Wang, Z., Shuai, S., Li, Z., &; Yu, W. (2021). A review of energy loss reduction technologies for internal combustion engines to improve brake thermal efficiency. Energies, 14(20), 6656. https://doi.org/10.3390/en14206656

Watts, A., Vallance, A., Whitehead, A., Hilton, C., &; Fraser, A. (2010). The technology and economics of in-wheel motors. SAE International Journal of Passenger Cars - Electronic and Electrical Systems, 3(2), 37–55. https://doi.org/10.4271/2010-01-2307

Winton, N., (2021a). Electric car sales will accelerate, but gasoline power will retain big global share. [online] Forbes. Available at: https://www.forbes.com/sites/neilwinton/2020/10/20/electric-car-sales-will-accelerate-but-gasoline-power-will-retain-big-global-share/?sh=29daec9f6705 [Accessed 5 Sep. 2023].

Winton, N., (2021b). Electric car sales will accelerate, but gasoline power will retain big global share. [online] Forbes. Available at: https://www.forbes.com/sites/neilwinton/2020/10/20/electric-car-sales-will-accelerate-but-gasoline-power-will-retain-big-global-share/?sh=29daec9f6705 [Accessed 5 Sep. 2023].

Woodford, C., 2023. How do flywheels store energy? [online] Explain that Stuff. Available at: https://www.explainthatstuff.com/flywheels.htmlgt; [Accessed 11 Oct. 2023].

Xia, T.,, Nitschke, M.,, Zhang, Y.,, Shah, P.,, Crabb, S., & Hansen, A., (2015). Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. Environment International, 74, pp.281–290.

Xiang, B., Wang, X. and Wong, W.O. (2022) 'Process control of charging and discharging of magnetically suspended flywheel energy storage system', Journal of Energy Storage, 47, p. 103629. doi:10.1016/j.est.2021.103629.

Yergin, D., 2021a. The major problems blocking America's electric car future. [online] The Major Problems Blocking America's Electric Car Future. Available at: https://www.politico.com/news/magazine/2021/08/31/biden-electric-vehicles-problems-yergin-507599 [Accessed 5 Sep. 2023].

Yergin, D., 2021b. The new map: Energy, climate, and The Clash of Nations. UK: Penguin Books.

Zhang, K.,, Schnoor, J.L., and Zeng, E.Y., 2012. E-waste recycling: Where does it go from here? Environmental Science amp;amp; Technology, 46(20), pp.10861–10867.

Zhao, G., Wang, X., Negnevitsky, M., &; Li, C. (2023). An up-to-date review on the design improvement and optimization of the liquid-cooling battery thermal management system for electric vehicles. Applied Thermal Engineering, 219, 119626. https://doi.org/10.1016/j.applthermaleng.2022.119626

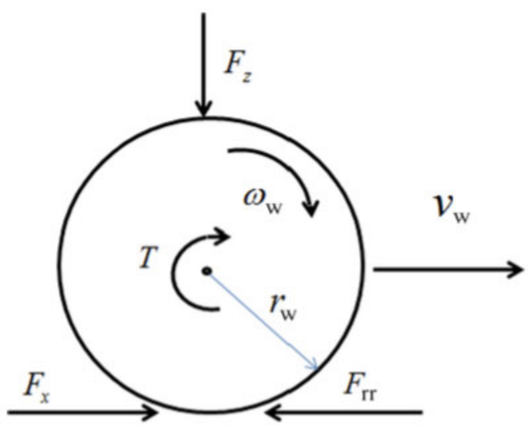
Zulkifli, S.A.,, Mohd, S.,, Maharun, M.,, Saad, N., and Aziz, A.R., 2012. Development of a retrofit split-axle parallel hybrid electric vehicle with in-wheel motors. 2012 4th International Conference on Intelligent and Advanced Systems (ICIAS2012).

8 Appendices

8.1 Tables & Diagrams

Physical Properties	Metric
Density	7.80 - 8.00 g/cc

Mechanical Properties	Metric
Hardness, Brinell	121
Hardness, Knoop	140
Hardness, Vickers	126
Tensile Strength, Ultimate	420 MPa
Tensile Strength, Yield	350 MPa
Elongation at Break	15 %
Modulus of Elasticity	200 GPa
Bulk Modulus	140 GPa
Poissons Ratio	0.25
Machinability	65 %
Shear Modulus	80.0 GPa



Physical Properties	Metric
Density	7.80 - 8.00 g/cc

Mechanical Properties	Metric
Hardness, Brinell	121
Hardness, Knoop	140
Hardness, Vickers	126
Tensile Strength, Ultimate	420 MPa
Tensile Strength, Yield	350 MPa
Elongation at Break	15 %
Modulus of Elasticity	200 GPa
Bulk Modulus	140 GPa
Poissons Ratio	0.25
Machinability	65 %
Shear Modulus	80.0 GPa

Table 5

(MatWeb, 2013)

8.2 Risk Assessment Documents

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland **Offline Version**

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	Hybrid retrofit for cars	Assessment Date:	23/05/2023
Workplace (Division/Faculty/Section):	School of Engineering	Review Date: (5 Years Max)	20/10/2023

Context			
Description:			
What is the task/event/purchase/project/procedure?	Research Project & prototype buil		
Why is it being conducted?	To understand more about cost and process of fitting electric motors to undriven wheels of passenger vehicles		
Where is it being conducted?	USQ Toowoomba Campus		
Course code (if applicable)	ENG4110	Chemical name (if applicable)	• • • • •
What other nominal conditions?			
Personnel involved	Matthew Brinkmann, John Billingsley		
Equipment	Computers, electric motors,Internal combustion engines, Batteries, Capacitors and associated ancillaries		
Environment	Workshop, home, test laboratories,maintained test track, natural environment		
Other	• • • • •		
Briefly explain the procedure/process	Perform calculations and experiments realted to research subject. Possibility of building a prototypoe system that utilises a mechanical battery.		

Assessment Team – who is conducting the assessment?	
Assessor(s)	Matthew Brinkmann

This document is uncontrolled once printed and may not be the latest version. Access the online SRMS for the latest version. Safety Risk Management Plan V1.1

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Stored electricity	Electrocution, electrical burns	Catastrophic	Ensure appropriate PPE is sued along with procedures when working with such equipment.Appropriately isolate electricity when not in use.	Possible	High	No	Barriers methods,	Moderate	Possible	Moderate	Yes
Fuel	Fire, burns, explosions, intoxication	Catastrophic	Ensure appropriate PPE is sued along with procedures when working with such equipment	Possible	Moderate	No	Use ventilation where appropriate, control amount of fuel used per test	Moderate	Possible	Moderate	Yes
Electric motor	Burns, electrocution	Catastrophic	Ensure appropriate PPE is sued along with procedures when working with such equipment.Appropriately isolate electricity when not in use.	Possible	High	No	Limit run time and load of electric motor	Major	Possible	High	Yes
Working in temperatures over 35°C	heat stroke, heat exhaustion, dehydration	Catastrophic	Ensure appropriate PPE is sued along with procedures when working in such conditions.Electrolite and hydration drinks made available. Temporary shelters to provide shade.	Possible	High	No	Limit time spent under such conditions. Work in pairs. Limit tasks that can be done in such contiions	Catastrophic	Possible	Low	Yes
Working in direct sunlight	heat stroke, heat exhaustion, dehydration, sun burn	Catastrophic	Ensure appropriate PPE is sued along with procedures when working in such conditions.Electrolite and	Possible	High	No	Limit time spent under such conditions. Work in pairs. Limit tasks that can be done in such contiions. Undertake work at times of dat when sunlight is less intensive.	Catastrophic	Possible	Moderate	Yes

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	Risk Level	ALARP? Yes/no		Consequence	Probability	Risk Level	ALARP? Yes/no
Example											
Working in temperatures over 35⁰ C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
			hydration drinks made available. Temporary shelters to provide shade. Skin appropriate sun block (ie fair skin more susceptable to sun burn.Sun Glasses, hats								
Fire	Burns, death	Catastrophic	water, foam, CO2, powder, water mist and wet chemical	Unlikely	High	Yes	Have fire fighting equipment nearby where fire may be present	Moderate	Unlikely	Moderate	Yes
Power tools	Injury to persons	Major	PPE, training proper use of powe tools	Possible	Moderate	Yes	Ensure first aid equipment is on hand at all times when operating power tools	Moderate	Possible	Moderate	Yes
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No

This document is uncontrolled once printed and may not be the latest version. Access the online SRMS for the latest version. Safety Risk Management Plan V1.1

Step 5 - Action Plan (for controls not already in place)

Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
Barriers	Protection barriers when undertaking experiments	Matthew Brinkmann	11/10/2022
Hot work gloves	Hot work glove	Matthew Brinkmann	11/10/2022
Face Shield	Face Shield	Matthew Brinkmann	11/10/2022
Fire Extinguisher	water, foam, CO2, powder, water mist and wet chemical	Matthew Brinkmann	11/10/2022
		Matthew Brinkmann	Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.

Step 6 - Approval

Drafter's name:	Matthew Brinkmann	Draft date:	24/05/2023
Drafter's comments:	This shall be reviewd and revised if necessary in 5 months time when the project shall commence		
Approver's name:	John Billingsley	Approver's title/position:	
Approver's comments:			
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			
Approver's signature:		Approval date:	Click here to enter a date.